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THE UNIVERSITY OF ALBERTA

ASSESSMENT AND MONITORING OF POTATO PLANTER PERFORMANCE

by

Ⓒ EDWARD JOHN HAUCK

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE
IN
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DEPARTMENT OF AGRICULTURAL ENGINEERING

EDMONTON, ALBERTA
SPRING, 1987

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(SIGNED) Edward J. Hauck

PERMANENT ADDRESS:

13903 88 Avenue
Edmonton, Alberta
Canada. T5R 4J1

DATED February 9, 1987

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and, recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ASSESSMENT AND MONITORING OF POTATO PLANTER PERFORMANCE submitted by EDWARD JOHN HAUCK in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

K. W. Domier

Supervisor

E. Rapp

Alan T. Andrew

Date March 12, 1987

Abstract

The metering aspect of potato planter performance was investigated in a set of experiments designed to determine the nature of pick-type metering mechanism interaction with seed potato pieces. Inconsistent delivery of seed pieces was identified as the primary factor behind the non-uniform planting patterns that have been identified with suppressed yields and inferior crop quality. Seed piece size and shape were determined to be critical factors in planter performance and seed piece yield potential.

In order to characterize the nature of pick-type planter metering performance, a laboratory experiment was conducted to study the effect of metering rate, and seed piece shape and size in relation to metering errors. Metering rates of 3, 6, and 9 plants/s were studied in combination with 45 g and 60 g seed pieces having 1, 2, or 3 cut surfaces. Higher metering rates were found to significantly decrease the occurrence of metering errors in the pick-type planter studied. Compatibility between seed material and the pick-type metering mechanism was also affected by seed shape and size. Blocky 3-cut pieces resulted in fewer metering errors when compared to the more rounded 2-cut and 1-cut pieces. Whole seed and 60 g seed pieces resulted in poor metering performance at metering rates below 6 plants/s. Consecutive metering error distributions are presented, for the performance factors studied, to facilitate the assessment of potato yields as

affected by planting patterns.

As a further step to understanding and improving potato planter performance, the design and development of a planter monitoring system was undertaken. The M6809 microprocessor-controlled potato planter monitor, with 2k of ROM and 2k of RAM, successfully employed a dual-sensor, event-triggered system to detect the occurrence of metering errors. Performance feedback to the operator included; immediate visual indication of metering errors for each planter row; intermittent visual display of performance statistics for each row; visual indication of drive train and sensor malfunction and audio indication of defective metering elements. The monitoring system performed to expectations on a potato planter simulation unit. Sensor positioning was determined to be critical for reliable performance.

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The author would like to express gratitude to the people who contributed to this thesis. The guidance and encouragement provided by Professors Ken Domier, William Andrew, and Jerry Leonard was deeply appreciated. As growers, Jack and Laverne Lewis offered an invaluable perspective and I thank them for the generosity they extended.

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1. INTRODUCTION

The Andes region of Peru and Bolivia between altitudes of 1,200 and 1,800 m is thought to be the potato's native home. History's first record of the potato, *Solanum tuberosum*, coincides with the Spanish conquistadors presence in Peru around 1524. The potato was first introduced to Spain somewhere between 1565 and 1580 and from there spread throughout the European continent reaching England by 1586. In the years spanning 1650 to 1840 the potato became a vital part of the Northern European diet, a fact brought to bear when the Irish potato famine struck during the 1840's. The first recorded evidence of the potato entering Canada was in 1623 at Port Royal, Nova Scotia where an English trading ship presented a barrel of potatoes to Acadian settlers (Thornton and Sieczka 1980). Since that time, potato production has flourished on Canadian soil.

On a world scale, potato production is increasing rapidly in the tropics and sub-tropics and is declining gradually in temperate zones (van der Zaag and Horton 1983). *Per capita* potato production estimates indicate that Eastern Europe (including Russia) is the largest consuming region but, unlike other regions, much of their crop is used as fodder. World consumption patterns indicate that 45 percent of the potato crop is utilized for human consumption, 31 percent as feed stock, 14 percent as seed, and 2 percent for starch (van der Zaag and Horton 1983).

Five year averages of Agriculture Canada (1985) statistics between 1980 and 1984 indicate that the total area under potato production in Canada is approximately 112,169 ha with an average yield of 26.2 t/ha. The yearly production of 2.9 million tonnes of potatoes has an estimated farm value of 306.1 million dollars. Approximately 78.2 percent of Canada's potato production takes place east of Manitoba with Prince Edward Island accounting for 28.6 percent of the national total. Alberta produces only 7.3 percent of the national total but has the third highest yield per unit area (26.6 t/ha).

The potato produces more edible energy and protein per unit area than most other crops and has a high level of daily energy and protein production (van der Zaag 1976). This high energy output is coupled with a very large energy input requirement that is exceeded only by that of irrigated rice. Today's production methods involve complex and highly specialized activities that have evolved over many years. Improvements in production practices have occurred in two ways: through reduction of production costs per unit area while maintaining yield, or by increasing yield without increasing production costs per unit area. Early potato research centered around cultivar trials, plant nutrition, disease-free seed production and the effect of spatial relationships on yield. In the 1950's the demand for processed potato products, such as French fries and chips (crisps), began to emerge and producers were encouraged to adopt market-specific production practices. Plant density concepts became more significant as grower desire for higher yields and consumer demand for product quality grew. Three factors of note in Glotzbach's (1973) assessment of European production trends between 1960 and 1970 during which time yields rose and area in production decreased were: changes in the production methods particularly in the control of weeds and potato blight by chemicals; the use of improved varieties and the use of high quality seed.

Aside from harvesting, stand establishment is the most expensive production operation for many crops. This is especially true where individual seeds must be isolated and placed at regular intervals (Harriott 1970). Since the late 1960's, potato planter performance studies have concentrated on improving irregular planting patterns and the rate of seed delivery as part of an overall desire to improve utilization of the agricultural resource base. As production methods intensified, the availability of agricultural labour and the ability to maintain a high work rate became increasingly important. To meet these demands, planter designs shifted from slow-speed, hand-fed planters to high-speed automatic units.

Plant stand surveys in the late 1960's (Andrew 1968) identified poor planter performance, as typified by inconsistent delivery of seed and irregular planting patterns, to be a major stumbling block for yield improvement. As the relationships between crop and planter performance became clearer, researchers began to investigate how properties of seed pieces affected yield from both an agronomic and planting operations point of view. Andrew and Domier (1978) believed the quality and yield of potato could be improved if relationships between potato seed, seed pieces, and planting techniques were better understood. Jarvis (1978) advocated that "any attempt to improve yield or otherwise increase the efficiency of the production process must be made with the requirements and limitations of mechanized systems in mind."

In light of the current understanding of potato planting operations, three objectives were set for this project:

1. To review planting parameters significant in establishing uniform and desired planting densities and to assess the planting density relationship to yield
2. To investigate the effect that metering rate, seed piece size and seed piece shape have on pick-type planter performance, and
3. To design a planter monitoring and data acquisition system capable of providing performance feedback to operators and for better evaluation of planting operations.

2. LITERATURE REVIEW

2.1 Seed Potatoes

Unlike many other vegetable crops, potato crops are usually established by vegetative propagation. Therefore, seed potatoes refer to the flesh of the previous generation. Due to the widely held preference for planting seed potatoes rather than potato seed, or true seed, the term seed will be considered synonymous to seed potato. One of the main reasons for not seeding true seed centers around the potato's diverse genetic constitution which represents a combination of 160 wild species and 20 cultivated species (Thornton and Sieczka 1980). No farmer can afford the uncertainty associated with such diversity on today's markets.

Next to the Netherlands, Canada is the largest seed potato exporter in the world with a distribution network extending to more than fifteen countries (Cameron 1984). Canada's cold winter climate offers some control over the spread of insects and diseases. Long-warm summer days and short-cool nights offer ideal conditions for high quality seed crops. The Canadian seed production system has six controlled and inspected tiers starting with pre-Elite I and II through to Elite I, II and III to Foundation, Certified, and ending with table grades (Agriculture Canada 1985). Of 65 licensed cultivars listed by Agriculture Canada (1985), Russet Burbank (formerly Netted Gem) is by far the most popular. Production estimates for 1984 indicate that Russet Burbank accounted for 37 percent of Canadian-grown seed. Developed in 1872 by Luther Burbank, Russet Burbank makes outstanding chips, is the standard for French-frying, bakes well, boils well, stores well, and is an all-time favorite. It is not surprising therefore to find a large proportion of North American potato research to be centered around Russet Burbank.

Seed potatoes are often the single highest input cost for potato producers. In South America and tropical Africa, seed potatoes represent 20 to 40 percent of production costs, in Asia, 30 to 55 percent and central America, 50 percent. European and North American producers spend approximately 20 percent of input costs on seed, 8 to 16 percent on labour, and 66 percent for other agricultural inputs according to van der Zaag and Horton (1983). Allen's (1978) estimates of seed costs in England are slightly higher at 30 to 50 percent of total growing costs. Seed quality is therefore a prime consideration in the production cycle. Aside from being disease free, quality parameters for seed lots include their physiological age and size distribution (Svensson 1977; Lidgett 1983).

The long-standing debate on the relative merits of planting whole seed *versus* cut seed originates from fundamental differences in North American and European production systems. To many European potato growers, the thought of cutting whole seed seems outrageous. The major criticism of cutting seed is the potential for spreading disease by means of contact with a contaminated cutting mechanism. Problems associated with seed cutting have been overlooked in light of the two major reasons for cutting seed.

Firstly, the majority of North American potatoes are grown on lighter soils (sandy loams, silt loams) that warm up rapidly in spring and have good drainage properties. Wetter, European soil conditions are more likely to cause cut seed to decay prematurely. The second reason has to do with the primitive state of the North American seed industry.

Canadian seed industry standards apply to all provinces whereas United States standards are set in each state. Although Canada is noted for quality seed, no designated seed producing areas are defined and control over the supply of seed is nonexistent. This implies two things to the seed grower: 1) the crop might not meet seed standards and, 2) if it does, it might be surplus to seed requirements (Rowberry and Howells 1979).

In both cases the most appealing alternative is to dispose of the crop as table-stock and this requires a minimum size of approximately 110 g. Seed of this size is too large to plant and must be cut into two, four or six pieces using a mechanical seed cutter. Rowberry and Howells (1979) concluded that given these conditions it seemed highly unlikely that North American producers would shift towards planting whole seed.

Molnar (1978) argued in favor of planting whole seed *versus* cut seed. His findings indicated whole seed had a greater total and marketable yield compared with cut seed of the same weight class. Total yield refers to the total harvested yield whereas marketable yield is the portion of total yield that falls within the standards set for different grades of marketable potatoes. The increased production of smaller potatoes was seen as advantageous, especially for seed production, even though this would necessitate alterations in planting practices, such as installing smaller chains on potato harvesters and slowing down the harvesting operation. Andrew and Silva (1983) demonstrated that cut end pieces from whole Russet Burbank potatoes had a marketable yield superior to whole seed tubers. Rempel's (1978) report agrees with this trend. Although Molnar (1978) predicted a significant shift from cut seed to whole seed on the Canadian prairies, the change, if any, has been slow to emerge.

The attention given to the description of seed material in planter performance studies ranges from nonexistent to excellent. Studies with poor or inadequate descriptions of seed make comparisons difficult. Unfortunately this aspect of planter performance has fallen victim to lack of experimental standards.

Svensson (1973) argued that productivity of potato seed would be improved by encouraging homogeneity within seed lots. Similarly, Thornton *et al.* (1983) suggested uniformity within seed lots would allow planters to perform more consistently.

2.2 Potato Growth Parameters

The complex nature of potato growth has been investigated from many angles with the objective of identifying significant growth parameters and their relationship to tuber yield. It is not the author's intention to detail all growth relationships as they are now understood. Rather, in pursuit of a more complete understanding of planter performance, an appreciation of the potato's agronomic relationships is necessary to realize the extent to which the planting process predisposes production potential.

A brief examination of potato morphology and anatomy is necessary to appreciate production relationships. The potato tuber is an underground stem that contains all the characteristics of a normal stem. Potato seed tubers possess a number of buds, or potential growing points, that are grouped together in eyes that tend to be concentrated at the apical end of the tuber (furthest from the seed). The buds at the apical end of a tuber exert apical dominance and normally sprout first at the end of dormancy. These buds are often referred to as the apical complex. Apical dominance is altered when a seed tuber is cut into pieces. The apical complex no longer exerts control over the whole tuber and this encourages sprout development from all pieces. Cut seed therefore has more main stems per unit weight than whole seed. Thornton and Sieczka (1980) suggest main stems from cut seed pieces tend to have a more uniform rate of emergence.

The number of buds that develop into stems depends also on the size and condition of the parent tuber (Allen 1978). Individual stems rely on the parent tuber to sustain growth for some time after emergence. Once stems become established, competitive interference for growing space and agronomic resources takes over.

Silva and Andrew (1985) point out the difficulty in achieving uniform potato crops. Up to 14-fold differences in tuber yield per hill were observed by these authors. Control over planting density has proven critical for establishing high yielding potato crops.

2.2.1 Population Density

Planting density can be manipulated by altering row or in-row spacing, seed piece size or shape, or seed conditioning. Therefore, the unit of density appropriate for describing the potato's yield response needs to be established. The most useful measures of planting density from Allen's (1978) perspective were the number of main stems/ha and weight of seed/ha. Iritani *et al.* (1983) considered main stems per unit area to be of limited value as a measure of density unless seed rate was also stated.

2.2.1.1 Seed Rate

Seed rate (t/ha) is the weight of seed planted per unit area and is equivalent to the number of tubers planted multiplied by the average seed piece weight. This is the unit of density most familiar to growers and has been used as the density scale in many existing density experiments (Allen 1978). Boyd and Lessels (1954) demonstrated how higher seeding rate increased yield. Their results also revealed distinct yield response curves for different sized seed grown in plots with identical seed rates.

A traditional method of assessing potato crops is the plant stand survey which compares the actual number of plants to the intended number of plants within a sample area. The resulting ratio, expressed as a percentage, is termed the plant stand. A plant stand survey conducted by Andrew (1968) over two years on 26 Alberta farms revealed plant stands ranging from 37 to 93 percent with an average of 74 percent. Further analysis of Andrew's 1968 stand survey was presented by Andrew (1971) and revealed that 60 percent of the factors responsible for reduced plant stands were attributed to missing seed pieces. An additional 19 percent of factors associated with poor plant stands fell into the wrong spacing or misplaced piece category. James *et al.* (1975) used aerial photography to assess plant stands in New Brunswick and found an average of 32 percent misses. Of the 1000 misses investigated, 88 percent were attributed to missing seed. Sieczka *et al.*'s (1986) three-year plant stand study again confirmed the failure to deliver seed as the major reason for missing hills and reported the average plant stand in New York State to be 83 percent. These studies appear to indicate that seed rates are substantially less than intended.

2.2.1.2 Main Stem Density

Holliday (1960) suggested that the main stem be considered the true unit of potato plant populations. A main stem was defined by Krijthe (1955) as a stem growing directly from the seed tuber. A positive relationship between the number of main stems per unit area of soil surface and yield was noted by Reestman and De Wit (1959). Another interesting observation from this study occurred at wide plant spacings where yield increased with the number of main stems per seed tuber and the total potato skin surface area. Results indicated a linear relationship existed between number of main stems per tuber and the tuber skin surface area. Both Bleasdale (1965) and Holliday (1960) claimed the stem number per seed piece was directly proportional to the number of eyes per seed piece and not related simply to skin surface area as suggested by Reestman and De Wit (1959). Wurr (1974) also reported a linear relationship between number of main stems per seed tuber and the number of sprouts before planting.

Allen and Wurr (1973) discussed methods of recording main stem densities in growing crops and conclude that differences between above-ground stems (includes auxiliary stems) and main stem counts were very small and unlikely to affect the relationship between yield and main stem density. A study by Iritani *et al.* (1983) confirmed this relationship.

Bleasdale (1965) claimed that the number of main stems per unit area influenced potato size distribution. Main stem densities from different sized seed tubers showed a continuous relationship for both total and graded yield whereas seed rates from different sized seed produced distinct yield response curves.

Wurr (1974) established a relationship between graded yield and main stem density. As main stem density increased, the total number of tubers was found to increase but the number of tubers per main stem, and the average tuber size, decreased due to greater inter-stem competition. The number of main stems produced by each seed tuber was found to be cultivar-dependent. Wurr, therefore, asserted that the larger the grade of potatoes over which yield is considered, the lower the main stem population required to give maximum yield in that grade. However, Lynch and Rowberry (1977a) reported that low main stem densities resulted in a higher proportion of deformed tubers.

Lynch and Rowberry (1977a) studied two reciprocal polynomial models for predicting main stem density/yield relationships over a wide range of densities (1.8-20 plants/m^2). The Bleasdale and Thompson (1966) model

$$y^{-\theta} = \alpha + \beta\varrho \qquad \ldots (2.1)$$

where y = yield/plant
ϱ = stems/m^2
α, β, θ = fitted parameters

appeared to give the most reasonable representation of the main stem density/yield relationship. Parameters α and β were associated with individual seed tuber sizes. Lynch and Rowberry (1977a) demonstrated that seed size did not influence the α and β parameters in cut and whole seed lots and, thus, they concluded that yield is a direct function of main stem density. Holliday (1960) identified the existence of an asymptotic relationship between the main stem density and total yield, and a parabolic relationship between marketable yield and main stem density. These findings were verified by Lynch and Rowberry (1977a) and are illustrated in Figure 2.1. The θ parameter in the Bleasdale and Thompson model was thought to characterize the

The title of Figure 2.1 is "Predicted yield/population density response curves for total and marketable yield in Russet Burbank (Lynch and Rowberry, 1977a)". This figure has been removed because of the unavailability of copyright permission. (Page 15) relationship between marketable and total yield since it represented a ratio of the weight of plant parts to the weight of the whole plant relative to changes in planting density. A value of one for θ represented the total yield response whereas a θ value of 0.5 was associated with the marketable response. The marketable yield response for growing conditions on the University of Guelph's experimental farm, as defined by Lynch and Rowberry (1977a), was 8.1 main stems/m^2 (Figure 2.1). Shotton (1976) also presented a marketable yield response curve that conformed to the Bleasdale and Thompson (1966) model.

Wurr and Morris (1979) found small tubers gave greater main stem densities per weight of tubers planted but the resulting marketable yield was not distinguished from total yield. However, they pointed out that the number of main stems produced from identical seed varies in different growing areas and suggested that causes of variation of main stem number per seed tuber be given a high research priority. Lynch and Rowberry (1977b) suggested that high planting densities reduced the rate of tuber growth due to increased intra-hill competition for available mineral and carbon assimilates. A growth analysis study by Collins (1977) found that, in plants with identical spacing, the growth rate of tubers from plants with two and four main stems were higher than those of single main stem plants. The resulting number of main stems and the average tuber weight proved to be higher for plants with four main stems.

Jarvis and Shotton (1971) realized that theoretical considerations of main stem density were of limited use unless the actual number of main stems produced in the field could be accurately predicted.

2.2.1.3 Seed Conditioning

Manipulation of seed tuber behavior can influence both the quantity and quality of yields. The term physiological age is often associated with seed conditioning and has been defined as "the physiological state of a tuber at any given time" (Iritani and Thornton 1984). Seed material is living plant tissue and, therefore, ages with time. The physiological age of seed potatoes influences emergence, main stem number, growth rate, maturity, tuber size and ultimately, crop yield (Knowles *et al.* 1985). Although the relationship between physiological age and main stem density is recognized, the lack of a precise definition and criteria for measurement make this concept difficult to quantify. The aging factor used by Fishman and Talpaz (1984) and Fishman *et al.* (1985) in their potato growth model was derived from commercial field data but showed considerable variation from crop to crop. A possible explanation for inconsistent derivation of the aging factor was attributed to its sensitivity to cultivation practices.

Iritani and Thornton (1984) suggest that the rate of aging depends on the growing environment of seed, storage environment, and field conditions during germination. Iritani *et al.* (1983) found the number of main stems per seed piece increased with higher storage and germination temperatures and with later planting dates. Knowles *et al.* (1985) reported that apical dominance, shoot vigor, percent plant stand, and total tuber yield all declined as seed tubers progressed in age past five months.

In Europe, pre-sprouted seed often is used in Europe to encourage early crop emergence. Experiments conducted by Shotton (1973) demonstrated a yield increase of 3.5 to 5 t/ha using pre-sprouted seed. Sprout damage is thus considered an important planter performance parameter in Europe.

Chemical applications to seed material can be used to augment or suppress the number of main stems per seed. Applications of napthalene acidic acid (NAA) at 100 mg/L to eight and twenty month old seed tubers was reported to increase yields by 8 and 11 t/ha respectively (Knowles *et al.* 1985). NAA applications to younger seed increased yield of larger tubers by reducing the number of shoots per tuber. Holmes *et al.* (1970) studied the effect of growth regulators on apical dominance and found that treating seed with gibberelic acid increased yield of seed-sized tubers by up to 70 percent due to an increased main stem number. Slomnycki and Rylski (1964) stated gibberelic acid affects whole and cut seed differently because gibberelic acid uptake through skin occurs at a much lower rate than through exposed flesh.

2.2.1.4 Seed Size

Many early potato experiments were concerned with the growth response of different seed tuber sizes. Recent seed-size research has focussed on the effect that seed mass per main stem has on graded yields. The degree of seed size variability in commercial planting operations and the limitations of seed cutters have led some extension programs to focus on the value of reducing size variability (Schotzko *et al*. 1984).

Wurr (1974) and Lynch and Rowberry (1977a) describe the relationship whereby larger seed pieces give a greater number of main stems per seed piece. Iritani *et al*. (1972) studied the relationship of yield to seed size, spacing, and main stem numbers using Russet Burbank potatoes. Identical main stem densities from different seed size spacing combinations were found to give variable proportions of U.S. No. 1 potatoes (112 g and over) and undersized potatoes. Larger seed spaced further apart averaged fewer main stems/unit area but produced a high marketable yield, superior plant stands and larger sized plants. A highly positive correlation (0.98) was established between weight of seed piece/main stem and total yield. The yield of different tuber grades as influenced by main stem number per seed piece (Figure 2.2) was reaffirmed by subsequent research (Iritani *et al.* 1983). Entz and LaCroix (1984) also found that crops grown from larger seed pieces with wide plant spacing had a higher marketable yield.

The initial rate of plant growth depends on the size of the seed piece and the rate at which the seed piece substrate is utilized (Milthorpe and Moorby 1979). In a growth analysis experiment, Dawes *et al.* (1983) showed that, once planted, seed piece weight decreased linearly with time reaching a 2 g residual mass 30 to 40 days later. Davies (1984) studied seed piece reserves as a limiting factor in potato sprout growth. His results indicated that, as the number of sprouts per seed tuber increased, the dry weight per sprout decreased due to increased intersprout competition. Wiersema and Cabello (1986) conducted research on comparative performance of different sized seed tubers. Increasing seed tuber weight decreased the time required for 90 percent emergence, increased the number of main stems per plant, increased the number of tubers per plant but decreased tubers per main stem, and increased total yields. Rowell *et al.* (1986) reported that use of 40-g to 60-g tubers resulted in

The title of Figure 2.2 is "Effect of main stem number per seed piece on yield of different sizes of Russet Burbank (Iritani and Thornton, 1984)." This figure has been removed because of the unavailability of copyright permission.

(Page 21)

yields 50 percent better than true potato seed possibly due to differences in early growth and emergence.

A seed piece survey by Andrew and Silva (1983) presented a range of average seed piece weights for different types of seed pieces found in seed lots on Alberta farms. For Russet Burbank, seed with one cut surface had a weight distribution between 34.1 and 66.0 g, seed with two cut surfaces were between 39.4 and 80.9 g, and seed having three cut surfaces fell between 41.8 and 90.3 g. A seed piece survey conducted by Schotzko *et al.* (1982) in Washington State found 15.5 percent of pieces weighed less than 28 g. The recommended seed piece size for Alberta conditions is 42 to 56 g (Andrew *et al.* (1976). The importance of defining seed piece size distribution rather than average seed size was stressed by Schotzko *et al.* (1984).

2.2.1.5 Seed Shape

The practice of cutting seed potatoes dissects the spherical-to elliptical-shaped whole tuber into a number of more blocky shaped seed pieces. As the size of the seed tuber increases, the number of seed pieces/tuber increases if an average seed piece size is maintained. However, the average skin surface area per piece decreases (Pitts and Hyde 1985).

Jarvis *et al.* (1976) concluded that spacing irregularity is best defined by the coefficient of variation (CV), consequently the CV is the most often used planter performance statistic. As defined by Steel and Torrie (1980) in equation 2.2, the CV represents a quantity that provides a relative measure of variation independent of the unit of measurement.

$$CV = \frac{s}{X} 100 \qquad \ldots (2.2)$$

where CV = coefficient of variation
s = sample variation
X = sample mean

Andrew and Silva (1983) investigated the influence of seed portion on main stem number. The term portion referred to place of origin on the parent tuber and, by implication, the number of cut surfaces or shape of seed piece. With Russet Burbank potatoes from three experimental sites, the average number of main stems on 1-cut (end) pieces was 3.3 compared with 2.4 main stems for 3-cut pieces. The coefficient of variation (CV) and plant stand were 52.5 percent and 66.7 percent respectively for 3-cut pieces compared to 33.0 percent and 95.0 percent for 1-cut pieces. These statistics are especially relevant considering that production costs for low yielding and high yielding hills were similar (Andrew *et al.* 1983). A cutting index developed by Silva and Andrew (1984) included a factor which diminished seed lot quality as the number of cut surfaces increased. Andrew *et al.* (1983) indicated that a greater proportion of high-yielding pieces could be achieved if more attention was given to adjustment of cutting equipment. Cutting related aspects of seed shape are discussed in section 3.3.2.

2.2.1.6 Planting Pattern

Row and plant spacings are chosen in light of many growth-influenceing factors. The ideal planting pattern would encourage vigorous and uniform crop development by providing the spatial arrangement of plants most suited for optimal utilization of agricultural inputs. However, defining and achieving the ideal planting pattern is indeed a difficult task.

Traditionally, row spacing was chosen for convenience and compatibility with the planter's power source. Row widths of 700 mm were used with horse powered cultivation but modern cultivation methods require 760 to 910 mm row spacing (Jarvis and Shotton 1972). Jarvis (1972) compared 760 and 910 mm row spacing and found total yields to be approximately equal but marketable yield was slightly higher at 910 mm spacing due to less wastage from tuber greening. With 910 mm rows, harvesting work rates improved by 16.7 percent and slightly lower levels of tuber damage were recorded. North and Proctor (1973) noted also that wider row spacing saved time during planting and harvesting operations and required lower depth of tilth to form the final ridge.

Choice of plant spacing is usually considered in conjunction with other population density parameters. Recommended in-row plant spacing in Alberta is 230 to 460 mm with wider spacing being more suitable where fertility and/or moisture are limiting factors (Andrew *et al.* (1976). Wilson (1970) investigated plant spacings between 300 and 510 mm in Maine and found total yield decreased as spacing increased. Marketable yield remained relatively constant due to an increase in tuber size and a decrease in tuber number.

Two contributing factors to irregular seed placement are failure to deliver seed, and inaccurate placement of seed. The discussion in section 2.2.1.1 established the extent of missing seed pieces in commercial crops. Discussion under section 2.6.1 examines the causes of irregular seed placement. This section considers the impact of irregular seed placement on yield.

Blodgett (1941) studied the reduction in crop yield due to diseased or missing plants. He established that plants adjacent to gaps, caused by missing seed, exerted a yield compensation effect. In a simulated gap study reported by Andrew *et al.* (1970) and Preston (1971), total and No. 1 yields from plants adjacent to as many as three consecutive gaps were progressively greater. No additional compensation was observed for 4, 5, or 6 consecutive gaps. Thus, yield reduction due to missing plants was not found to be proportional to the percentage of plant stand loss. Yield compensation was a result of increased tuber size, not tuber number. This was evident as total and marketable yields per unit area were lower when the number of consecutive gaps was increased. However the yield of No. 1 potatoes increased slightly with 1 or 2 gaps and then decreased gradually up to 6 gaps. James *et al.* (1973) and James *et al.* (1975) assessed yield reduction attributed to missing plants by examining losses due to reduced plant stands. The 1973 study concluded that 90, 80, and 70 percent plant stands in New Brunswick crops resulted in 0, 5.6, and 11.1 percent reduction in yield respectively.

Jarvis *et al.* (1976) investigated differences in total and marketable yields attributed to spacing irregularity at CVs of 0, 20, 40 and 60 percent, at three different population densities. Total yield decreased and marketable yield fell by 1.7 t/ha when the CV was increased from 0 to 60 percent. As the CV increased so did the proportion of large tubers. Although yield depressions were not large, they were thought to be economically significant. Pascal *et al.* (1977) and Entz and LaCroix (1984) disagreed, stating that a CV as high as 75 percent did not reduce yield.

Some sites in Robertson and Pascal's (1974) study suggested irregular planting patterns may even be beneficial to yield. Davies (1954) and Boyd and Lessells (1954) demonstrated irregular spacing had a negative effect on yield only at very wide mean spacings while Sieczka *et al.* (1986) stated that non-uniform distribution of seed depresses yield only when the CV exceeds 100 percent.

Bleasdale and Thompson (1966) studied the impact of one, two and three plants in the same hill and concluded that seed clumping had little effect on yield.

Therefore, non-uniform planting patterns appear to have the most significant impact when planters produce a consistent pattern of consecutive planting errors. This reduces both effective planting rate and the compensation effect of plants adjacent to misses. Hirst *et al.* (1973) and James *et al.* (1975) pointed out the importance of defining a frequency distribution for consecutive misses since yield reduction is a function of the frequency in each consecutive miss class.

2.2.2 Economic Assessment of Growth Parameters

Schotzko *et al.*'s. (1982) review of the economics of seed size and spacing assessed the value of attainable yield, as defined by van der Zaag (1984), lost due to non-uniform planting patterns on Washignton State potato farms at $400/ha. Using Alberta Agriculture's (1982) economic assessment of fresh potato production, this represents an increase in the return to management of 59 percent.

Sharpe and Dent (1968) studied the economics of planting density. The planting density for optimum economic returns occurred at the point where the cost of establishing a main stem and the marginal value product equalled one another. Costs per main stem are related to the price of seed and the average number of main stems per seed piece which, in turn, depends on the weight distribution of whole seed tubers, seed conditioning, and cutting. Schotzko *et al.* (1984) discussed the economic impact of Russet Burbank seed size and spacing using a typical processor contract. Their economic assessment of yield proceeded in much the same manner as Sharpe and Dent's (1968) analysis.

Jarvis *et al.* (1976) pointed out that small variations in main stem densities which produce maximum yields have little effect on marketable yield due to the flat-topped nature of the marketable yield response curve (Figure 2.3, point A.) However, the ability to compensate for small variations in main stem density is more sensitive at a lower density which defines the point of maximum economic returns (Figure 2.3, point B). This case becomes even more critical if the established main stem density is less than intended (Figure 2.3, point C), as appears to be the case on many North American potato farms.

The title of Figure 2.3 is "Economic assessment of the marketable yield response curve (Jarvis et al, 1976". This figure has been removed because of the unavailability of copyright permission. (Page 29)

2.3 Seed Handling

The degree of variability in seed size and shape together with the dynamic nature of interactions between seed and both planter and growing environment, make seed piece uniformity a primary objective of the cutting process (Thornton *et al.* 1983). Mass production of seed pieces can be viewed as two separate operations: the grading of whole tubers according to size, and the cutting of each size in an appropriate manner.

2.3.1 Grading

Potatoes are often graded on potato cutters to facilitate the cutting of seed tubers according to size. Grading is also used to separate potatoes into the market grades established by processors and marketing organizations. The potato's vulnerability to damage and its diversity in size and shape impose a strict set of demands on the grading process.

Most on-farm graders and potato cutters have a series of parallel rollers with variable apertures capable of separating tubers into small, medium or large sizes. The major problem with roll sizers is that sizing is done by the smaller tuber dimension rather than the larger one (Pitts and Hyde 1985). As the proportion of large tubers increases, the load factor on the cutter's sizing rollers also increases. This reduces the efficiency of separation and increases the amount of tuber damage (Klenin *et al.* 1985).

The maximum feed rate for roller graders was given by Klenin *et al.* as 3.0 to 5.3 kg/s per metre of width. Grader capacity was defined as

$$q = 3.6\, q_o\, B \qquad \ldots (2.3)$$

where q = capacity of the grader (t/h)
q_o = maximum feed rate (kg/s·m)
B = width of the grading surface (m)

Zhao *et al.* (1986) stressed the importance of sizer roller spacings for effective separation of seed tubers. A simulation model designed to study the effects of different cut widths and roller spacings illustrated the sensitive nature of sizer roller adjustments. For the chosen distribution of whole seed cut to standard widths, the proportion of desired seed (28 to 84 g) decreased by 5.4 percent and the oversized seed increased by a similar amount when sizer roller spacings were increased by 6 mm.

The shape of the potato is the most critical parameter when considering roller spacing (Zhao *et al.* 1986). Johnston (1970) correlated whole tuber diameter with weight and found the relationship to be cultivar-dependent. Webster's (1970) shape index (equation 2.4) was significant at the 1 percent level when used to discriminate between cultivars.

$$\text{Tuber shape index} = \frac{Tl\ 100}{Tb} \qquad \ldots (2.4)$$

where Tl = tuber length
Tb = tuber breadth

Brown's (1973) shape index (equation 2.5) is based on all three tuber axes and, therefore, gives a slightly more accurate index for cultivar shape.

$$\text{Tuber shape index} = \frac{Lmax\ Lmin}{Ce^2} \qquad \ldots (2.5)$$

where Lmax = maximun length of circumference
Lmin = minimum length of circumference
Ce = equatorial circumference

McRae (1985) reviewed work by Kolchin and Semekhunov (1975) who concluded that tubers sorted by weight had a scatter of linear dimensions smaller than the scatter of weights when tubers were sorted by linear dimensions. Goryachkin (1974) also supported the idea of sorting tubers by weight rather than sorting by linear dimensions.

McRae (1985) presented an equation for potato volume as

$$V = K\ a\ b\ c \qquad \ldots (2.6)$$

where V = potato volume
K = 0.524 for a true ellipsoid
a = length
b = breadth
c = thickness

Pitts and Hyde (1985) studied two ellipsoid-based models to predict volume, one considered all three axis and the other assumed the two larger axes to be equal. They concluded that the volume of a whole tuber can be calculated within five percent if the tuber length and width are known:

$$V = \frac{4 \pi a b2}{3} \quad \text{... (2.7)}$$

where V = tuber volume
a = 1/2 major axis
b = 1/2 minor axis

The Canadian seed tuber sizing schedule, in place as of 1983, had three size designations "A", "B", and Contract size. "A" sized tubers ranged from 113-340 g for round cultivars (e.g. Norchip) and 113-454 g for long cultivars (e.g. Russet Burbank). "B" sized tubers ranged from 42-113 g for both round and long cultivars. Contract size was defined as any size range agreed to by the buyer and seller. The proposed sizing regulations presented by Lidgett (1983) would see tuber sizing reported according to linear dimensions (based on the ability to pass through different sized square mesh) rather than weight. Equivalent sizes for the new long cultivars would see "A" sizes as 50-80 mm and "B" sizes as 40-50 mm. "A" sizes for round cultivars convert to 60-90 mm and "B" sizes to 40-60 mm. Another interesting aspect of the proposed changes is a minimum seed size of 25 mm for long cultivars and 28 mm for round cultivars (Lidgett 1983). These dimensions represent weights around 14 g and present an unexplored market for small seed.

Pascal *et al.* (1977) and Thornton *et al.* (1983) found closely graded whole seed resulted in a more uniform planting pattern. Planting graded seed (45-55 mm) was recommended by Eddowes (1986) for accurate seed spacing and depth of placement.

Sands and Regal (1983) introduced the concept of the tuber weight grading function to describe the distribution of weights of individual tubers. The grading function is a cumulative probability distribution function based on the assumption that tuber weights, in a population of mature potatoes are normally distributed. As such, the grading function can be described by the population's mean and standard deviation. Each grading function has a corresponding probability density function which can then be used to predict the fraction of yield between any two weights.

The benefits derived from the grading process should also consider the cost of tuber damage due to handling (McRae 1980).

2.3.2 Cutting

Seed cutters were classified by French (1958) as automatic or non-automatic. Automatic cutters are self feeding and were further classified as "B" splitters or multiple sizer cutters. Non-automatic machines require an operator to position tubers prior to cutting. Most potato growers use high speed multiple sizer seed cutters to accommodate the cutting of large seed tubers into 2, 3, 4, or 6 pieces, depending on the tuber size.

Nomenclature for seed piece shape tends to vary and often reflects the researcher's focus. Andrew and Silva (1983) described seed pieces as whole, apical end, basal end, center cut, 3-cut, and quarter, all which imply a shape or position of origin on the parent tuber. Pitts and Hyde (1985) were concerned with optimizing cutting pattern for different sized tubers and chose seed piece names based on how many pieces a specific cutting pattern produced; 1-cut, 2-cut, and 4-cut. All naming schemes relate a pattern of increasing cut surface area and decreasing skin surface area, or, a change in shape from spheroid to blocky. Each shape influences the main stem number per seed piece and compatibility with the planting process. These relationships are central to an integrated perspective of planting operations.

The distribution of seed piece shapes and sizes within seed lots on Alberta potato farms (Andrew *et al.* 1983) showed substantial variation. This appears consistent with observations by Boyd and Lessells (1954) who noted considerable differences in weight of seed planted from farm to farm. Large ungraded whole seed contributes toward lack of seed piece uniformity (Johnston 1970; Hauck *et al.* 1982) as does the type of cutter and spacing of sizer rollers (Andrew *et al.* 1983).

According to French (1958) seed piece quality depends on the uniformity of seed piece size and the incidence of seed pieces without eyes. Leach *et al.* (1972) recommended that tubers over 280 g not be used for seed and, if they were, hand cutting was recommended. French (1958) reported that the cost of cutting seed depends on the percent of oversized tubers. Red Pontiac tubers cut into six pieces were found to be devoid of eyes 5 percent of the time whereas tubers cut into eight pieces had a 25 percent eyeless rate. Therefore, larger, longer, and less uniform seed decreases the homogeneity of seed piece size and shape (Pitts and Hyde 1985). Andrew *et al.* (1983) reported these conditions increased crop variability.

Optimal cutting patterns for different tuber sizes were derived by Pitts and Hyde (1985). As the number of seed pieces cut from one tuber increased from 2 to 7, the cut surface area to skin surface area ratio increased from 0.53 to 1.51. The volume of a seed piece as defined by Pitts and Hyde (1985) is given in equation 2.8.

$$SPVOL = \frac{\pi b^2}{N}\left(X - \frac{X^3}{3a^2}\right)\Bigg|_{X_{low}}^{X_{high}} \qquad \ldots (2.8)$$

where SPVOL = seed piece volume
X high = right end of seed piece
X low = left end of seed piece
N = the number of cut surfaces
a = 1/2 major axis
b = 1/2 minor axis

The cut surface area of a seed piece as defined by Pitts and Hyde (1985) is given in equation 2.9.

$$CSA = \frac{\pi}{N}\, b\, \left(2 - \frac{X_{high}^{\;2} + X_{low}^{\;2}}{a^2}\right) \qquad \ldots (2.9)$$

where CSA = cut surface area

Skin surface area as defined by Pitts and Hyde (1985) is given in equation 2.10.

$$SSA = \frac{2\pi}{N}\, b \frac{\sqrt{a^2-b^2}}{a^2} \left(\frac{X}{2}\sqrt{\frac{a^4}{a^2-b^2} - X^2} + \frac{a^4}{a^2-b^2}\, \mathrm{Sin}^{-1}\, \left(\frac{X}{a^2}\, \sqrt{a^2-b^2}\right)\right)\Bigg|_{X_{low}}^{X=X_{high}} \qquad \ldots (2.10)$$

where SSA = skin surface area

Because a seed potato entering the cutting mechanism cannot be positioned accurately, the production of undersized seed pieces, or slivers, is inevitable. Slivers produce plants lacking vigor and therefore sliver removal devices should be used in conjunction with the cutting operation (Thornton *et al.* 1983).

Zhao *et al.* (1986) investigated two methods of reducing the variation in cut seed size: modification of seed cutters, and elimination of undersized seed pieces. They found that increasing the width between cutting blades increased the percent of desired Russet Burbank seed pieces to a maximum after which the proportion of desired seed dropped off rapidly. The criteria used to define desired seed pieces was based solely on weight (28-84 g) and ignored any shape effects. Adjustments to sizer roller spacings were shown to alter the size distribution of tubers approaching the cutting mechanisms. Although the optimum combinations of cut width and sizer roller spacings produced 90 percent desirable seed for an assumed seed size distribution, the optimum combination was noted to change with cultivar and size distribution of seed stock. Andrew *et al.* (1983) supported the view that growers can increase the proportion of desirable seed by adjusting cutting equipment according to seed lot size and shape. Implementing optimum settings in practical situations is difficult due to a combination of human error, inflexible cutter design, and the lack of proper indicator mechanisms for sizer roller spacings (Hauck *et al.* 1982).

The second part of Zhao *et al.*'s (1986) study examined the possibility of pneumatic separation of undersized seed pieces. Both percent loss of desired seed pieces (28-84 g) and percent separation of undersized seed pieces were measured as a function of air velocity in wind tunnel experiments. For the size distribution of seed pieces studied, the best results were achieved at an air velocity of 24.4 m/s where 80 percent of the undersized seed was separated with less than 4 percent of desirable seed lost. Factors which proved significant to seed terminal velocity were the height of end pieces, and mean diameter of half pieces. The terminal velocity of middle pieces (27.4 m/s) was well above the optimum separation velocity (24.4 m/s).

Seed cutting invariably is done at the storage site either at the time of planting or prior to planting to allow sufficient time for seed pieces to suberize in storage. Suberization refers to the healing process that takes place on freshly cut seed piece surfaces. Cutting seed at the time of planting is acceptable if soil conditions are favorable for healing cut surfaces and has the added advantage of preventing cut seed from rotting in storage should a stretch of inclement weather interrupt planting operations (Thornton and Sieczka 1980). Timm *et al.* (1973) concluded that healthy seed pieces with uniform respiration rates could be produced if seed potatoes were cut well in advance of planting to allow for suberization to take place. Their recommendation for cut seed storage was a shaded and ventilated environment with a temperature of 25°C to 30°C. Thornton's and Sieczka's (1980) recommendations are slightly different as they suggest suberization is best achieved by holding cut seed for three to five days at temperatures between 12.8°C to 18.4 °C with a relative humidity of 85 percent. Properly cut and stored seed pieces are reported to keep for two or three weeks without losing vigor (Rowberry and Howells 1979).

If a fungicide is required, the application is usually in powder form and is applied as pieces leave the cutter or in the field just prior to planting. One of the factors attributed to irregular planter performance is the tendency for seed pieces with greater cut surface area to stick to one another and to planter components (Likhyani *et al.* 1981). Research on the interaction between seed delivery systems and freshly cut *versus* suberized seed piece does not appear to have been studied.

2.4 Potato Planters

2.4.1 Types

Commercial potato crops in Europe and North America are planted by mechanical planters which open the soil, place the seed at the desired depth and spacing, and then cover and firm the seed bed. Planters usually have two, four, or six rows. Some one and two row planters use a three-point tractor hitch and utilize the tractor power takeoff to drive the metering mechanism. However, most planters rely on ground driven wheels to power the metering mechanism.

Planter operation, maintenance, and adjustment are more significant to planter performance than the type or make of planter (Andrew and Preston 1969). The basic components of the potato planter as outlined by Breece (1975) are: carrying and drive wheels; seed hopper; fertilizer hopper; fertilizer disk opener; fertilizer feed mechanism; platform; furrow opener shoe; covering disks; markers; and planting and feeding mechanisms. A brief examination of planter components will provide an overview of the planter's function.

Towed planters have two drive wheels that provide power to the fertilizer and planting mechanism. Wheel hubs are usually bolted to the drive axle with shear bolts to avoid damage to the planter should the metering mechanism jam. Carrying wheels are often found on six and eight row planters. The flow of seed from the hopper to picker chamber is controlled by adjustable gates. A platform on the back of many planters provides a space for an operator to monitor planter performance and to carry out duties dictated by planter design. Furrow openers consist of a set of opening disks and a wedge shaped opener shoe mounted on an undercarriage with hydraulic depth control. Planting action creates a furrow 75 to 100 mm wide in the seed bed. A set of covering disks for each row are located on the rear of the planter. These disks cover the seed and hill the row according to pitch and height adjustments relative to furrow openers.

Potato planters are most often classified according to their metering or feeding mechanism. Reference categories, based on operator labour requirements, refer to planters as manual, semi-automatic, or automatic (Jarvis 1978). Metering mechanisms are classified broadly as positive or non-positive mechanisms (Maunder 1983) depending on whether seed is individually selected and released or merely dispersed.

Early hand-fed planters required an operator for each row to select a potato from trays or bulk hoppers before dropping the seed down the planting tube. Planting rate was governed by ground speed and operator work rate. Improvements to hand-fed units included conveyance devices with compartments that transferred seed to the soil surface at regular intervals. Spacing was a function of both operator efficiency and conveyance speed relative to ground speed.

Cup-type planters select seed from the seed reservoir with cups mounted on an endless chain or belt. As the belt or chain travels through the planting tube, seed is conveyed toward the soil surface on the back of the preceding cup. Early planters used steel cups while some recent models offer plastic cups and inserts to meet different sizing requirements. The cups on many early models were designed to pick up only one seed. In some models, a compensation mechanism was used to release seed when a miss was encountered. Later models had larger cups capable of picking up more than one seed. Extra seed was displaced back to the seed reservoir with a removal device. Further developments included two to four rows of cups for each row planted. This allowed the belt to travel at slower speeds and resulted in superior metering performance. Spacing was determined by the speed of the belt or chain relative to ground speed.

Flat-belt planters direct the flow of seed from the hopper to a metering mechanism which feeds tubers onto a set of horizontal belts. The belts then discharge the tuber backwards onto the soil surface. Spacing proved to be a function of feed rate onto the belts and consistency of delivery.

Moulded-belt planters function in a similar manner to flat-belt planters. The belt consists of a series of moulded cups each capable of holding one tuber. Operators are required on the planter to ensure proper filling of cups.

Tuber unit planters combine both cutting and planting tasks. Belts travelling at different speeds align whole tubers before they are cut and then dispense the resulting pieces.

Pick-type planters usually have two vertically-mounted picker wheels for each row. The six to eight picker arms on a picker wheel each have a set of picks that pierce seed pieces as the arms rotate through the seed reservoir. When picker arms approach the planting tube, a cam activated stripper pushes the seed piece off the picks allowing the seed to fall down the planting tube and into the furrow.

Variation in pick length and arrangement offers some flexibility in accommodating different seed characteristics. Spacing is controlled by varying picker wheel speed relative to ground speed. A potential problem with this type of planter is the spread of disease from successive puncturing of seed pieces.

The new fully automatic Smallford Setronic potato planter developed by the Scottish Institute of Agricultural Engineering (Carruthers *et al.* 1984) combines many existing design concepts and adds microprocessor control to the seed delivery system. Plant spacing is push-button selected and achieved by microprocessor control of the hydraulic motor driving the planting belt in relation to ground speed. Three sets of belts are used for each row. A feed belt travels through the hopper in a direction perpendicular to the furrow filling the six moulded cups arranged across its width. The set of six seed tubers are then transferred intermittently onto a planting belt traveling toward the back of the planter. Each tuber falls into a separate flight on a planting belt and then is transferred to the point of release. Photo cells at the point of transfer between feed and planting belts detect empty cells which then are filled when make-up belts on the downstream side of the planting belt are activated. An infra-red detector above the make-up unit ensures that a tuber is available by indexing until a tuber is detected.

2.4.2 Safety

Safety concerns surrounding potato planters are focused on planter operators and their prescribed tasks. Semi-automatic planters require the operator for each row to pick and place the seed into the metering mechanism whereas automatic planters are more likely to have an operator standing on a rear mounted platform acting as a trouble-shooter and communication link to the tractor driver. In Murphy's (1980) unsafe behavior model, relationships between operator conditioning, rare event, and decision making are outlined. Operator conditioning relies on the principle of reinforcement. The belief that an accident will not occur encourages the operator to make the decision perceived to be of greatest utility. For the planter operator this could mean ensuring a constant seed feed by disrupting bridging action with a poke stick, or knocking doubles from metering elements, or perhaps by fishing stones from the seed reservoir bowl as the planter proceeds down the field. Prairie Agricultural Machinery Institute (PAMI) evaluation reports E1077 (1978a) and E1178A (1978b) both mention the importance of using a suitable poke stick to avoid injury to the operator.

Monitoring systems on field machinery enable operators to shift their attention away from simple tasks which can be tedious and time consuming. Design innovations "to improve the degree of personal safety during operation and application of products and materials" are part of the agricultural engineer's responsibility (Davis 1980). Electronic monitoring of problem areas would reduce the need for planter operators and, therefore, accidents are not as likely to occur.

2.5 Planting Operations

A majority of North American potato farms plant potato pieces cut from whole tubers using picker arm planters (Sieczka *et al.* 1986). The ability to perform at high planting rates with a minimum labour requirement accounts for the pick-type planter's popularity. Cup-type planters are gaining in popularity and are the planter of choice on most seed farms where disease control and regular planting patterns are critical. European producers prefer cup-type or belt-type planters to accommodate the planting of whole and, often, sprouted seed.

Date of planting varies between regions and years depending on soil moisture, soil temperature, and target market. Suggested minimum soil temperature at planting depth is 7°C (Andrew *et al.* 1976; Thornton and Sieczka 1980). Cold and wet conditions may contribute to seed piece decay and result in poor plant stands. Dates for planting in Alberta vary from early to late May depending on local conditions. High market prices for early crops provide incentives for producers to accept the risk of early planting and intensive management techniques.

Careful soil preparation is necessary to provide favorable growing conditions and facilitate ease of soil separation during harvest operations. Pre-planting cultivation is done just prior to planting. Cultivators with vertically rotating blades are often used because they have good depth control and provide the desired qualities of a fine textured seed bed with small aggregates (Poesse *et al.* 1973).

Insufficient planting depth results in tuber greening if tubers are exposed to sunlight. Suggested depth of planting is 80 to 130 mm below level ground (Andrew *et al.* 1976). If the height of the hill is considered, seed tubers should lay 150 to 200 mm below the top of the hill (Thornton and Sieczka 1980). Irregular depth control is often a problem with wide planters on hilly terrain.

From the farm management perspective, potato planting is noted for its slowness compared to other crops. The importance of planting rate is emphasized by the negative effect delayed planting has on yield. Increased planting rates enable machinery and labour to be reassigned to other seasonal demands. The higher potential output of modern planters requires that more attention be put to non-productive activities such as refilling the hopper (Jarvis 1978; Rowberry and Howells 1979). In Britain, traditional methods of filling the planter's seed hopper can account for up to 50 percent of planting time. Maunder (1983) studied seed handling systems in Great Britain. Seed in bulk containers resulted in planter filling rates of 3-5 man-min/t whereas handling seed in trays took 10-20 man-min/t. North American filling practices usually make use of a self-unloading potato truck and a towed transfer conveyer mounted at right angles to the truck's direction of travel.

The labour force required to run a smooth planting operation is dependent on the capacity and labour demands of planting machinery together with the size and type of farm operation and management style. Shotton's (1976) evaluation of different types of potato planters mentions an association between planter type and labour usage. However, due to the diversity in management styles and labour costs, the type of planter did not determine labour requirements. If minimum labour requirements for the planter are considered, clearly an advantage lies with larger, more automated planters.

2.6 Planter Performance

Concern over planter performance became firmly established when planter design shifted from hand-fed to automatic units. Sieczka *et al.* (1986) stated that "the primary reason for poor plant stands was the misplacement or failure to plant seed pieces." With increased work rates and faster planting speeds, new planter designs created questions about acceptable levels of irregular spacing and stimulated the investigation of performance factors. Maughan

(1973) saw performance data as a means to compare machines and as a reference point for decision making. According to Maughan, performance assessment should study the ability to segregate individual seeds from the seed reservoir and the suitability of soil-working parts. Maughan concludes "it is, however, unwise to study one of the aspects without due consideration of the other."

The approach to planter performance studies has evolved through the years. Studies by Pascal and Provan (1969), Jarvis and Palmer (1973) and Robertson and Pascal (1974) correlated planters and planter trials with yields. Although measures of planter performance were given, control over variations in planting, growing, and harvest phases of production were very difficult and results often were inconsistent or incomplete. Studies by Pascal and Langley (1971), Johnson and Vogt (1973), Carruthers (1975), Klassen (1977, 1980), Misener (1979, 1982), Likhyani *et al.* (1980), and Sieczka *et al.* (1986) used seed position in the furrow as a basis for performance comparisons. Knowing the pattern of seed distribution enabled yield response to be inferred from studies on growth response to spatial arrangement.

Halderson (1981) suggested a suitable approach for row-crop planter evaluation involving a separate analysis of metering and placement performance. Metering performance gives a measure of the metering mechanism's ability to engage a single seed at every opportunity whereas placement performance relates the effectiveness of seed transfer from the planter to its intended resting point in the furrow. Hyde *et al.* (1979) and Hyde and Thornton (1980) collected metering performance data using stationary planters driven by a variable speed electric motor. The dynamics of seed placement were presented in a paper by Bufton *et al.* (1974). Andrew and Domier (1978) and Pitts and Hyde (1985) suggested that consideration should be given to an integrated view of the planting process where interactions between seed, planter, and planter operating conditions determine performance. Jarvis (1978) stated that "an awareness of the nature of the general problems associated with the potato crop is a necessary adjunct to the planning of any research and development project on the crop."

2.6.1 Irregular Seed Spacing

One of the traditional measures of planter performance is the uniformity of the planting pattern. Several different statistics and methods of assessing spacing uniformity appear in planter performance literature. These include the coefficient of variation (CV), partial frequency distributions based on intended spacing, a performance index based on performance limits, and graphical renditions of successive seed spacing. These measures are based on the distribution of spacings between successive seed pieces and thus are a combined measure of metering and placement performance.

2.6.1.1 Measures of Uniformity

Jarvis *et al.* (1976) noted that, with hand-fed and cup-type planters, gaps between plants had a normal distribution and, therefore, irregularity of spacing could be defined in terms of the standard error of mean spacing except when the degree of irregularity is high and mean spacing is low. The standard deviation of a mean is often called the *standard error* (Steel and Torrie 1980). Jarvis *et al.* state further that assessments of crops planted at different mean spacings with the same planter suggested the standard error of the distribution of spacings varied with the mean spacing although this is not clearly established. However, other studies do not support the claim that the standard error of the spacing varies with mean spacing. For instance, Misener (1979) found that an increase in plant spacing decreased the frequency of doubles and skips for cup-type and pick-type planters. Likhyani *et al.* (1981) demonstrated that plant spacing did not significantly alter cup-type, and pick-type, planter performance.

If spacing errors do not necessarily vary with the mean spacing, then using the CV as a means of comparing performance trial results is invalid, unless, trials are conducted with identical plant spacings. This is so because the CV varies inversely with the sample's mean spacing. Therefore, larger spacing results in smaller

CVs, given a constant standard deviation of spacing. This point can be illustrated using data from Carruthers's (1975) planter trials. Both mean spacing and CV for planter trial runs are recorded. Knowing these statistics, the standard deviation of the spacing can be calculated using equation 2.2. For Pentland Dell graded to 32-37 mm, a spacing of 303 mm gave a CV of 37.5 percent and a standard deviation of 114 mm. However, an almost identical standard deviation of 112 mm at 390 mm spacing gave a CV of 29.2 percent. Although the standard error of seed placement is virtually identical for both trials, the CV indicates the 390 mm spacing is more uniform, and this is clearly not the case.

Performance studies by Misener (1979), Sieczka *et al.* (1986), Pascal and Robertson (1975), Pascal and Langley (1971), Carruthers (1975), and the Prairie Agricultural Machinery Institute (PAMI) (1978a, 1978b, 1978c, 1979, 1980) also used CV as a measure of spacing uniformity.

Likhyani *et al.* (1980) and PAMI publications (1978a, 1978b, 1978c, 1979, 1980) report irregular spacing as a frequency distribution using spacing categories. Four spacing categories are considered: doubles, singles, misses, and double misses. Likhyani *et al.* (1980) defined doubles as seed pieces less than half the intended spacing away from the preceding piece, singles are between half and one half the intended spacing, misses occur at one and a half to twice the intended spacing, and double misses at greater than twice the intended spacing. Misener's (1979) definitions differ. A miss is defined as a gap equal to or greater than twice the intended spacing and a double as a gap less than 70 mm. Again, caution has to be exercised when using these statistics to compare planter trials with different plant spacing. In the definition of a single, the acceptable deviation from the mean will change by half the change in the intended spacing. Thus, larger intended spacings will have a greater number of singles and doubles and fewer misses and double misses. Likhyani *et al.* (1981) acknowledged this, stating that the difference between 59.9 percent singles for pick-type planters and 44.2 percent singles for cup-type planters can not be considered significant because different spacings were used. The definitions of the above-mentioned spacing categories are inconsistent in PAMI potato planter performance reports. This makes performance comparisons difficult.

A study conducted by Johnson and Vogt (1972) used a performance index to evaluate planters. This index penalized the planter for wrong spacing and delivery of more or less than the intended number of seed. Unfortunately, the derivation of index values was not discussed.

Performance studies by Klassen (1977, 1980) give a graphical rendition of successive seed spacing. The pattern generated when the distance between seed pieces was plotted for consecutive seed pieces provided an effective method of illustrating placement pattern but is statistically inconclusive.

2.6.1.2 Accuracy Standards

Arbitrarily established standards for planting uniformity have been used to set acceptable limits to spacing variability. In Sweden, the recommended planting accuracy (Larsson 1986) allows for a maximum of 2 per cent gaps, 5 per cent doubles and a CV for plant spacing in the 20 to 40 per cent range. A CV of less than 40 percent is the acceptable level of seed placement uniformity in PAMI's (1978) evaluation reports. Johnson and Vogt (1973) suggested that 90 percent of seed should be within 76 mm of intended spacing and that 95 to 105 percent of the intended amount should be delivered. Of twelve planting operations surveyed by Johnson and Vogt, not a single operation met these standards. Experimental work by James *et al.* (1973) suggested that a seeding rate achieving a 90 percent or better plant stand is satisfactory.

2.6.1.3 Planter Type

Planters vary in their ability to maintain consistant plant spacing. Table 2.1 lists planter performance (CV), in the literature cited, according to planter type.

Pick-type planters tend to plant fewer doubles and at low spacings have less misses compared to cup-type planters (Misener, 1979). Investigations by Shotton (1976) indicated that high delivery rates are possible with belt-type planters but often at the expense of greater variation in seed spacing. Jarvis and Palmer (1973) compared yields from cup-type and belt-type planters to hand-fed planters. Compared to hand-fed planters, Jarvis and Palmer (1973) found that cup-type planters reduced yields by 1.6 t/ha and, belt-type planters were associated with a 2.6 t/ha yield reduction.

2.6.1.4 Planting Speed

The effect of speed on row crop planting patterns varies with seed material and the type of metering mechanism (Hofman *et al.* 1986). An evaluation of 8 planters over 196 trial runs by Misener (1979) demonstrated that ground speeds from 4 to 8.8 km/h reduced accuracy of cup planters but pick-type planters did not exhibit the same sensitivity to speed. Averages from 64 trial runs conducted by Likhyani *et al.* (1981) supported these findings and although an increase in

Table 2.1 A review of potato planter performance according to planter type

Planter type	Seed type	CV(%)		Source
		range	average	
Hand-fed	Whole	15-59	33.1	English Agricultural Development and Advisory Service (1975)
	Whole	20-30		Jarvis (1978)
Belt-type	Whole	55-86		Pascal and Langley (1975)
	Whole	20-30		Jarvis (1978)
Moulded-belt	Whole	24-55	35.6	English Agricultural Development and Advisory Service (1975)
Flat-belt	Whole	29-90	46.9	English Agricultural Development and Advisory Service (1975)
Tuber-unit	Cut	48-71		Misener (1982)
Cup-type	Whole	15-41	33.1	English Agricultural Development and Advisory Service (1975)
	Whole	15-25		Jarvis (1978)
	Whole		66.0	Prairie Agricultural Machinery Institute (PAMI), (1979)
	Cut	59-87		Misener (1979)
	Cut		64.0	PAMI (1979)
	Cut		70.9	Likhyani et al. (1981)
Pick-type	Whole	48-69		Sieczka et al. (1986)
	Cut		31.0	PAMI (1978a)
	Cut		28.0	PAMI (1978b)
	Cut		38.0	PAMI (1978c)
	Cut	55-69		Misener (1979)
	Cut		61.0	Likhyani et al. (1981)
	Cut	43-70		Sieczka et al. (1986)

speed from 5 km/h to 8 km/h was not significant, the number of singles increased by 2.2 percent for pick-type planters but decreased by 10.2 percent with cup-type planters. The pick-type planter's apparent performance improvement with higher speeds was attributed to the greater penetrating force exerted by the picks.

Laboratory studies by Hyde and Thornton (1980) reported that cup-type planters tend to deliver more than the intended number of pieces at low ground speeds. The pick-type planter examined by Hyde and Thornton showed no effect of speeds below 5 km/h but increasing the speed to 8 km/h resulted in a significant increase in seed spacing.

In planting trials conducted by Sieczka *et al.* (1986), three pick-type planters were observed at various ground speeds under 6.5 km/h. Although planter operation varied considerably, no distinct pattern emerged. One planter was tested for uniformity of spacing with whole seed. At 4.5 km/h, the CV was 48 percent but at 6.5 km/h the CV increased to 69 percent. This decrease in uniformity was attributed to seed bouncing off picker arms rather than being properly pierced and released.

A performance study on a belt-type planter using whole seed (Pascal and Langley 1971) indicated that increasing speeds from 7.2 to 10.4 km/h increased both spacing CV and mean spacing. The belt-type planter developed by the Scottish Institute of Agricultural Engineering, as described by Carruthers (1975), was also reported to increase mean spacing at higher speeds.

2.6.1.5 Seed Size and Shape

Observations by Johnson and Vogt (1973) indicate that planter performance can be affected by the geometric characteristics of seed pieces, especially when using cup-type planters. The first description of cut seed piece shape related to planter performance appears in a study by Likhyani *et al.* (1981). Hand cut potato pieces, from Norland (round) and Russet Burbank (long) cultivars, weighing 40 g and 60 g had shapes described as end pieces or center cuts.

Most performance studies describe seed as whole or cut and if cut, whether cut by hand or by machine. Studies which fail to give an accurate account of seed characteristics included Klassen (1977; 1980), and the 1968 and 1969 trials reported by Sieczka *et al.* (1986). In trials conducted during 1970 and 1971, Sieczka *et al.* (1986) recognized the importance of controlling seed size and used hand-cut tuber pieces weighing 57 g. Johnson and Vogt (1973) used seed pieces weighing greater than 56 g and acknowledged that size and shape of seed pieces had an undetermined influence on their results. Hyde *et al.* (1979) gave a tuber mean weight of

36.4 g and noted seed was smaller than desired for cup-type planter trials. Mean weight and standard deviation of cut seed are given by Hyde and Thornton (1980) as 42 g and 18 g. Misener (1982) gave a description of seed pieces used for each planter tested. Mean weights ranged from 33.1 g to 50.1 g and standard deviation ranges from 12.0 to 17.6.

Carruthers (1975) categorized whole seed according to cultivar shape (flat round, oval, long oval) and grade (32-44 mm; 44-57 mm; and 32-57 mm). Pascal and Langley (1971) used tubers graded either to 34-42 mm or 42-51 mm and describe cultivar shape as round or long-oval.

The PAMI potato planter evaluation reports E1077 (1978a), E1178A (1978b), and E1178B (1978c) use seed with an average weight of 40.0 g. PAMI report number E0579 (1979) deals with cut and whole seed with an average weight of 60 g. In PAMI report E0480 (1980), average cut seed weight was 70 g. All PAMI trials used Russet Burbank potatoes.

Misener (1982) noted the importance of matching seed piece and cup sizes on cup-type planters after observing a decrease in misses and doubles with larger seed. A pick-type planter's level of spacing uniformity appeared to be not as sensitive to seed size. Tuber unit planters produced more misses when planting large whole tubers. Likhyani *et al.*'s (1981) investigation on the effect of seed piece size and shape found no significant difference in performance between 40 g and 60 g seed pieces. The shape of seed piece proved to be highly significent with end cut pieces averaging 59.8 percent singles as opposed to 43.8 percent for center cut pieces. Both Klenin *et al.* (1985) and Pitts and Hyde (1985) stated that irregular seed placement is greater for seed pieces with non-uniform size distributions.

Effect of whole seed size on spacing uniformity with belt-type planters was proven to be insignificant by Carruthers (1975). Pascal and Langley (1971) also reported that whole tuber shape had no apparent effect on mean spacing for belt-type planters. Misener (1982) suggested that accuracy of seed placement improves in cup and pick-type planters when planting whole seed. In Siecczka *et al.'s* (1986) planting trials, whole seed tubers planted with a a pick-type planter gave the best seeding rate but also resulted in the least uniform seed distribution pattern. The seed shape and planting speed interaction is discussed futher in section 2.6.4 under placement performance.

2.6.2 Seeding Rate

The ability to deliver the desired amount of seed over a given area is more important than the uniformity of seed spacing (Sieczka *et al.* 1986). Seed rate (t/ha) can be used to measure a planters ability to meet the desired seed spacing if the average seed size is known.

Factors such as wheel slip on drive wheels, large numbers of misses and doubles, broken or damaged metering elements, and bridging action in the hopper or feed mechanism all contribute to deviations from desired seed rate. Consequently, the actual average seed spacing often differs from the intended spacing. Theoretical seeding rate is defined by equation 2.11 given by Hunt (1986).

$$P = \frac{10,000\ N\ R}{2\ \pi\ r\ (1-s)\ w} \qquad \ldots (2.11)$$

where P = the number of seed pieces/ha
N = the number of metering elements per revolution of the metering mechanism
R = the ratio of revolutions of the metering mechanism for every revolution of the drive wheel
r = effective radius of drive wheel (m)
s = drive wheel slippage (decimal)
w = effictive row width (m)

The actual seeding rate can be calculated by multipling the theoretical seeding rate by the ratio of successful metering events to total metering events.

The results from planting surveys by Sieczka (1986) and Klassen (1980) indicated that actual seed spacing was 40 mm greater than intended. The five PAMI potato planter evaluation reports (1978a, 1978b, 1978c, 1979, 1980) report average spacing deviated from the 460 mm intended spacing by

30, -20, 5, -10, 15 mm. All but one evaluation indicated that average spacing increased with speed. Hyde *et al.* (1979) noted that mean seed spacing increased with speed, lower picker bowl levels and location of picks closer to the picker wheel. The plant stand surveys discussed in section 2.2.1.1 lend support to the fact that seed application rates are generally lower than intended.

2.6.3 Metering Performance

If factors contributing to irregular planting patterns are partitioned according to planter function, then a separate analysis of metering and placement performance is in order. Expressing metering performance as a function of metering rate is quite acceptable, however, relating metering performance in terms of ground speed means little without stating levels of other significant planting parameters.

Four methods of assessing metering performance are reported in the literature cited. Burema *et al.* (1975) used a moving sticky belt below a mounted precision planter to gather spacing data. Slow motion 16 mm movies were used by Sieczka *et al.* (1986) to observe the planting process. Hyde *et al.* (1979) used a photo cell and light source at the drop chute to detect a falling seed. A 16 lobed cam was attached to the picker wheel drive shaft such that each passing picker arm closed a cam-switch. Electrical pulses from both sensors were connected to a chart recorder allowing metering statistics to be collected.

Compatibility between metering elements and seed material is of primary importance to regular seed delivery. Pick arrangement was determined to be significant by Hyde *et al.* (1979). The three different pick arrangements studied produced deviations from the intended spacing of -9.0 mm, 6.7 mm, and 23.2 mm. Johnson and Vogt (1973) found a three-pick arrangement to deliver 97 percent of intended seed compared to 88 percent for a two pick arrangement. Klenin *et al.* (1985) found that optimal clearance between picker spoons and the side plate of the feed hopper depended on the mass of the seed tuber. Clearance between the outer edge of the metering elements and the bottom of the feed hopper influence the amount of seed piece damage. Recommended clearance values were 3-5 mm.

Hyde and Thornton (1980) examined sprocket and roller idlers and three different idler spring tensions on cup-type planters. Both idler types delivered less seed as spring tension was increased. This was especially evident with the sprocket idler, which agitated the cup chain more vigorously.

The level of seed in the seed reservoir showed a positive correlation with the amount of seed delivered per unit time (Hyde *et al.* 1979; Hyde and Thornton 1980). Klenin *et al.* (1985) suggest that a seed depth 100 to 150 mm in the seed reservoir is needed to meet the metering demand and avoid excessive seed damage caused by higher levels.

The value of applying the kinematics of planting units to planter design is stressed by Bufton *et al.* (1974) as he states "where a forward speed is required which achieves an acceptable rate of work, optimization of the seed release conditions is only likely to be achieved by specific drill design to overcome the problems posed by metering mechanisms being unable to satisfactorily meter seeds at higher peripheral speeds."

2.6.4 Placement Performance

Seed displacement after impact with the soil surface depends on the nature of the soil surface, weight and shape of the seed piece, impact velocity, and impact angle (Bufton *et al.* 1974). Although an analysis of placement performance for seed potato pieces does not appear in the literature cited, sugar beet seed was among the seeds investigated by Bufton *et al.*

The interaction between seed velocity and the angle of impact indicated greater seed displacement with lower impact angles (relative to the soil surface) and higher seed velocities. Angles of impact above 40° resulted in a progressive decrease in mean seed displacement to a minimum which occurred between 75-80° for all seeds studied (Bufton *et al.* 1974). Lower angles of impact increased seed displacement, especially for spherical seeds and heavier irregular shaped seeds. Seed roll was more prevalent on packed *versus* sheared soil surfaces.

The horizontal component of seed velocity is the main factor behind seed piece roll and is equal to the horizontal component of the metering mechanism's peripheral velocity and the velocity of the planter. Pascal *et al.* (1977) substantiate the problem of greater seed piece roll at high planting speeds. If the soil working parts of the planting mechanism were designed to trap the seed piece at the point of impact, seed roll would be negligeable.

The kinematics of picker planting units, as presented by Klenin *et al.* (1985), are used to relate design parameters to field operating conditions. The kinematic index is defined by Klenin *et al.* (1985) as the ratio of the linear velocity at the extreme point of the metering mechanism to the speed of the machine (equation 2.12).

$$\lambda = \frac{u}{v} = \frac{2 \pi R}{z s} \qquad \ldots (2.12)$$

where λ = kinematic index
u = linear velocity at extreme point of metering mechanism
v = ground speed of the planter
R = length of planter arm
z = number of metering elements
s = plant spacing

For a given spacing and planter speed, the number of cups or picker arms on the metering mechanism can be selected using the kinematic index. Ideally the kinematic index assumes a value of -1. In this case the horizontal velocity of the metering mechanism at the point of release is equal and opposite to the speed of the planter, thus, the horizontal component of seed velocity is zero. This condition minimizes the tendency of seed pieces to roll upon impact with the soil.

2.7 Planter Monitoring and Instrumentation

The production of agricultural commodities depends on the efficient use of resources. As critical resources become more expensive, producers need to assess alternatives and determine the implications of altering the production system (Smith *et al*. 1985; Holt and Schoorl 1985).

A historical review of instrumentation on agricultural equipment by Wilson (1983) noted that, until recently, this subject had gone virtually unnoticed and was not particularly well documented. The evolution of planter instrumentation and monitoring systems were given as examples of progress in this field. Mechanical switches activated by falling seed have now been replaced by infra-red light emitting diodes, photo transistors and magnetic and capacitive proximity sensors. Analogue circuits are now often supplemented with digital circuitry. Flashing lamps, needle gauges, and warning buzzers are no longer the exclusive means of indicating machine performance. Ongoing and user-requested performance levels now can be transmitted to the operator through an array of output devices which include alphanumeric displays.

Modern monitoring and control systems are based on microprocessor ability to analyse a series of events over a period of time. Wilkins (1979) discussed microprocessor control of precision planters.

Thornton *et al.* (1983) assert that an optimal set of planting parameters are difficult to identify considering the combinations of planter operating conditions and the variable nature of potato growth response. Performance feedback was identified as a means of encouraging satisfactory performance levels. PAMI evaluation report no. E0579 (1979) recommended that manufacturers provide the option of a planting monitor to accommodate the needs of a one-person potato planting operation. A microprocessor controlled modified belt-type potato planter developed by Carruthers *et al.* (1984) used an array of photo cells to detect and replace empty cells with potatoes from a secondary delivery system.

Other examples of electronic assistance in potato planting operations include seed flow and hopper level indicators (PAMI 1980), a microprocessor assisted system for grading potatoes (Carlow 1983), and an automatic load control system for conveyors (Hyde *et al.* 1983).

3. ASSESSMENT OF PICK-TYPE PLANTER METERING ERRORS

3.1 Objective

The objective of this experiment was to determine how metering rate, and seed piece size and shape, affect metering performance of pick-type planters.

3.2 Equipment and Experimental Facilities

Laboratory planting trials were conducted at the University of Alberta's Agricultural Engineering Research Station at Ellerslie.

A McConnell 555 single-row, ground driven pick-type planter (Figure 3.1), manufactured by McConnell Mfg. Co. Inc., Prattsburg, New York, formed the experimental unit. The pick-type metering mechanism had a picker wheel with sixteen picker arms. Each picker arm had two steel picks (Figure 3.2) that pierced seed pieces as the picker wheel rotated through the seed reservoir. Seed was released by the cam-activated stripper device on each arm.

The data collection system consisted of an IBM Personal Computer, a Datataker model DT100 data logger manufactured by Data Electronics (Aust.) Pty Ltd. and a sensor system capable of detecting successful and unsuccessful metering events. Picker wheel action and sensor positioning are illustrated in Figure 3.3.

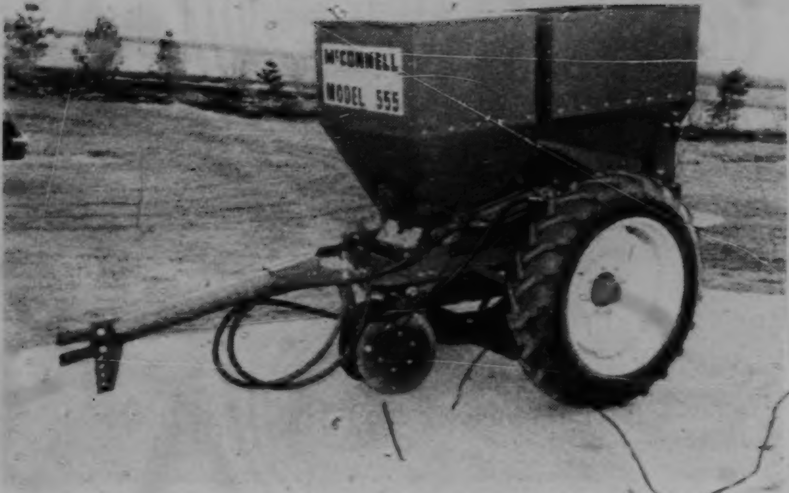

Figure 3.1 McConnell 555 pick-type planter

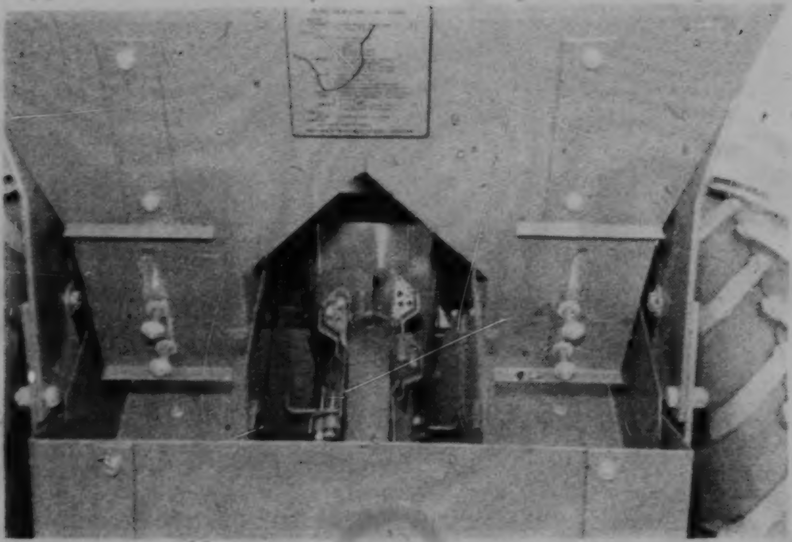

Figure 3.2 Pick-type metering mechanism

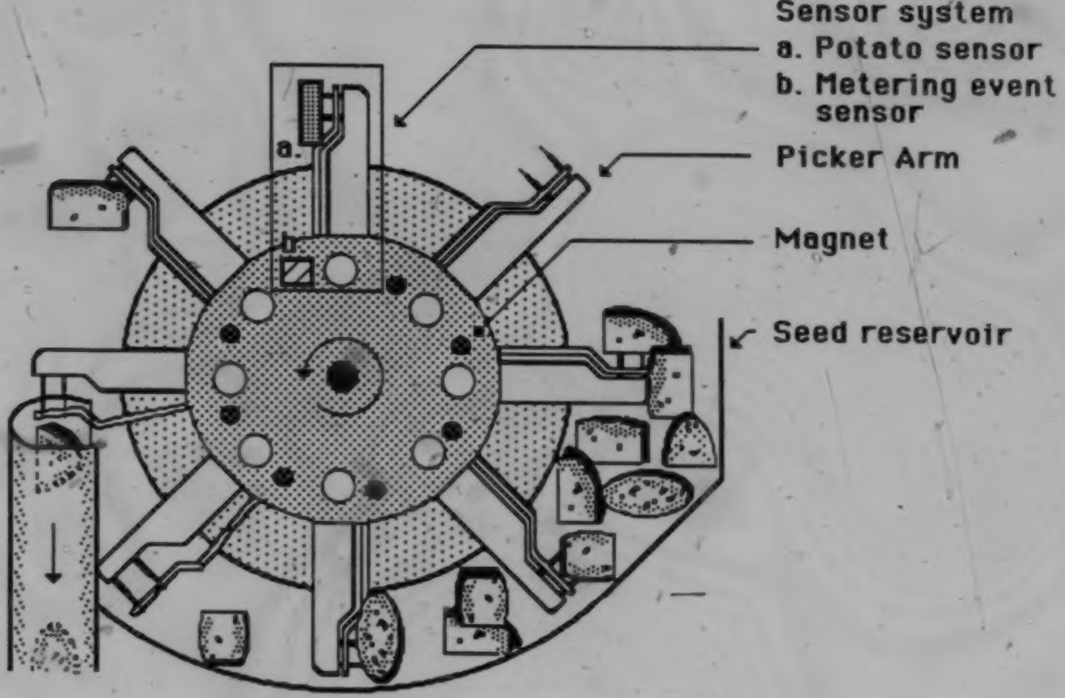
Sensor system
a. Potato sensor
b. Metering event sensor
Picker Arm
Magnet
Seed reservoir
a.
b

Figure 3.3 Picker-wheel action and sensor positioning

3.3 Experimental Procedure

A total of 105 laboratory metering trials were conducted using a McConnell pick-type planter, mounted on blocks and powered by a variable speed electric motor. Two experiments were conducted. The first experiment assessed metering performance of cut seed using a 3 x 3 x 2 factorial experimental design (randomized complete block, with five replications). Three metering rates were investigated in combination with three seed piece shapes and two seed piece sizes. Moderate to high metering rates were chosen with 3, 6, and 9 plants/s representing field speeds of 3.8, 7.6, and 11.4 km/h at 30 cm plant spacing. Seed shapes and sizes were chosen to be representative of seed found on Alberta potato farms. Shapes having one, two, or three cut surfaces were investigated in combination with seed sizes of 45 g and 60 g.

The experimental layout for whole seed metering trials was based on a single criterion of classification for groups of data with equal replication. Metering performance of 50-100 g whole seed at metering rates of 3, 6, and 9 plants/s was determined.

3.3.1 Seed Preparation

Whole Russet Burbank seed tubers with a mean weight of 178 g and a standard deviation of 68.7 g were hand cut into 6 seed lots weighing 45 kg (±5 kg). Each seed lot represented a seed shape and size combination. A seventh seed lot weighing 45 kg (±2.5 g) consisted of whole tubers between 50 g and 100 g. Seed piece shapes are described as 1-cut, 2-cut, or 3-cut to reflect the number of cut surfaces as illustrated in Figure 3.4 (a). Figure 3.4 (b) shows the portion of the parent tuber from where seed pieces of a particular shape originated. Seed piece shapes were cut to 45 g and 60 g (±2.5 g) sizes bringing the number of seed lot treatments to 6. Each whole seed tuber and the resulting pieces were individually weighed with a scale having accuracy to 0.1 g. Seed dimensions defined as variables in equation 2.8 (Pitts and Hyde (1985)) were measured with an accuracy of ±2.5 mm.

3.3.2 Planter Preparation and Instrumentation

The planter was mounted on blocks and the wheels were removed. A sprocket and chain drive assembly with a 5:1 reduction ratio was installed between the drive wheel hub and the output shaft of a 10:1 reduction gear box powered by a 0.75 kW variable speed electric motor (model 2BD-01154, Leeson) rated between 0 and 1750 rpm. A baffle board was placed below the point of seed release to deflect falling seed into a collection box used to recycle seed for metering trial replications.

Metering errors were detected using a dual-sensor, event-triggered system. Sensor system positioning and mode of operation are illustrated in Figures 3.3 and 3.5. A modulated infrared through-beam photoscanner (model MCS-651,

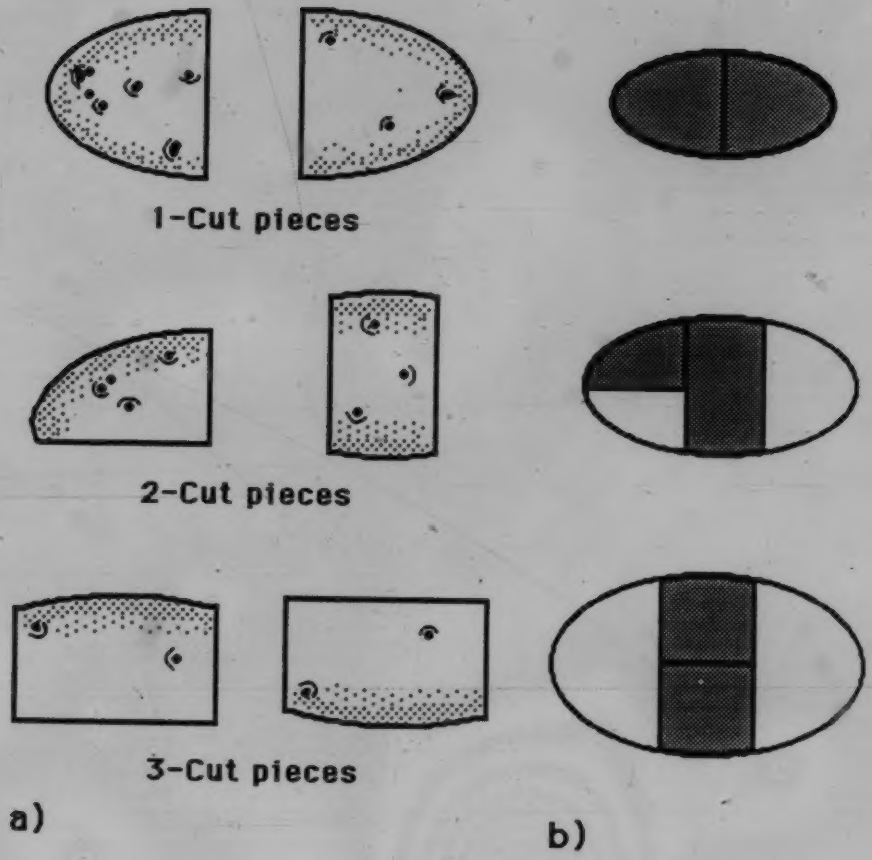
1-Cut pieces
2-Cut pieces
3-Cut pieces
a)
b)

Figure 3.4 Cut seed attributes
a) Seed piece shape
b) Seed portion

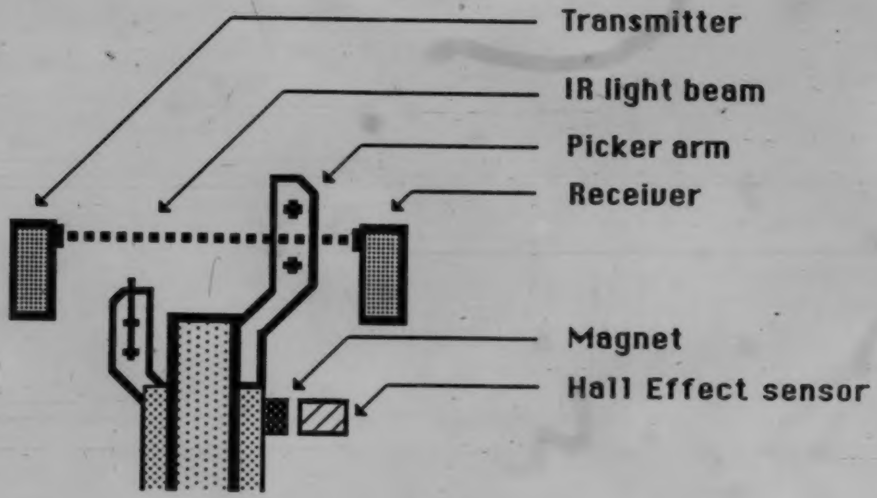
Transmitter
IR light beam
Picker arm
Receiver
Magnet
Hall Effect sensor

Figure 3.5 Sensor system

Warner Electric, Marengo, IL.) functioned as the potato sensor and was mounted so that the light beam intersected the plane of picker wheel rotation at right angles and passed halfway between the two picks on the picker arm. Permanent ceramic magnets 13 mm in diameter and 7 mm thick were bonded to the base of each picker arm, with the south pole facing outward, along a line extending from the mid point of the pick's length to the picker wheel hub. A Sprague 3019T Hall Effect switch (metering event sensor) was positioned so the leading edge of a passing magnet would create a pulse indicating the occurrence of a metering event at precisely the moment that picks on the picker arm passed through the potato sensor's light beam. A gap of 4 mm between the metering event sensor and the magnet gave very precise metering event signals. The sensitivity of the metering sensor was improved by bonding another magnet's north pole to a 5 mm thick plastic spacer which in turn was fixed to the back of the metering event sensor. This arrangement concentrated the magnetic field surrounding the Hall Effect switch and allowed the metering signals to be triggered from a greater distance.

Both the metering event sensor and the potato sensor were connected to the data logger which in turn was connected to the IBM PC. An on-off toggle switch (data log switch) completed the data acquisition circuit. Section 4.2.1.2 contains further sensor system discussion and Appendix E9 and E10 provide sensor circuit diagrams.

3.3.3 Collection of Metering Data

After a randomly chosen seed lot was placed in the seed hopper, data logging instructions were sent from the IBM PC to the data logger. Once the variable speed electric motor was set to the desired metering rate, a contact tachometer (Tak-Elete, model 1707, Power Instruments Inc.) was used to confirm picker wheel speed. Logging of metering data commenced when the data log switch was engaged. As the magnets on passing metering elements signalled metering events, logic circuitry on the light sensor was polled to determine if a potato piece was engaged (beam broken - logic 1) or if a metering error had occurred (beam intact - logic 0). Logic voltages then were logged. Any bridging action that threatened to disrupt the flow of seed was broken up with a stick, to ensure a constant feed rate. After a minimum of 100 metering events the data log switch was disengaged. Metering data was transferred from the data logger to a data file on disk and then the hopper and seed reservoir were emptied. This procedure was repeated for five replications of seed lot treatments.

3.3.4 Data Analysis

Seed piece data were analysed to determine the cut and skin surface areas as defined by equations 2.9 and 2.10 (Pitts and Hyde (1985)). The ratio of cut surface area to skin surface area gives a continuous measure of cut seed attributes as opposed to the number of cut surfaces which provides a discrete but less effective characterization of seed material.

A metering data analysis program written in BASICA (Appendix A) was used in conjunction with an IBM PC to analyse data files. The first three data points in each file were disregarded to eliminate inconsistency which may have resulted when the data logger was engaged. Each line in the data file contained a "1" or a "0" which represented either a successful or unsuccessful metering event. The total number of metering events and the number of successful and unsuccessful metering events were determined. A distribution of consecutive metering errors was established by recording the number of consecutive misses preceding each successful metering event.

3.4 Experimental Results and Discussion

Sensor positioning effects were not verified beyond comparing the observed metering performance and the metering error indicatior (a light emitting diode (LED) on the data acqusition circuit). Errors were more prevalent at lower metering rates. The overestimation of metering errors could have been avoided had the potato sensor been positioned to intersect the plane of pick rotation at the tip of the picks upon a metering event signal, rather than half way down the length of the pick.

No indication of sensor system malfunction was evident for over 20,000 recorded metering events.

3.4.1 Seed Piece Attributes

Seed piece dimensions were analysed to determine the seed piece volume (equation 2.8), cut surface area (equation 2.9), and the skin surface area (equation 2.10) as defined by Pitts and Hyde (1985). Unfortunately dimensions recorded with ±2.5 mm accuracy did not predict seed piece weight accurately as determined by the product of predicted seed piece volume and the potato's specific gravity. Consequently cut and skin surface area calculations were of little value.

3.4.2 Metering Results

A summary of cut and whole seed metering trial results are presented in Table 3.1 (summary of Appendix B1 and B2 respectively). Metering performance was measured in terms of metering errors or the percent of total metering events which were unsuccessful. Table 3.2 (summary of Appendix B3) and Table 3.3 (summary of Appendix B4) sets out the distribution of consecutive metering errors, expressed as a percentage of total metering errors, for cut and whole seed respectively.

3.4.2.1 Relation of Seed Shape to Metering Errors

The analysis of variance presented in the ANOVA in Table 3.4 indicated metering rates, and cut seed shape and size, were significant at p = 1 percent. Of the first-order interactions, metering rate x shape and metering rate x size interactions also proved to be significant at p = 1 percent but the seed shape x size

Table 3.1 Metering performance summary

Percent of metering events which were unsuccessful *				
Seed attributes		Metering rate (plants/s)		
Size (g)	Shape	3.0	6.0	9.0
45	1-cut	26.6	27.0	31.6
	2-cut	29.7	22.4	13.4
	3-cut	25.9	11.4	10.1
60	1-cut	63.0	31.5	16.5
	2-cut	38.7	24.3	21.2
	3-cut	28.3	16.1	15.9
50-100	whole	55.4	30.8	14.0

* Average for 5 replications
(minimum of 100 metering events for each replication)

Table 3.2 Distribution of consecutive metering errors for cut seed

Percent of total metering events which were unsuccessful *										
	Consecutive metering errors									
	1	2	3	4	5	6	7	8	9	10
Metering rate										
3 plants/s	12.7	7.6	4.7	3.5	1.3	1.2	1.6	0.1	0.4	0.4
6 plants/s	12.4	5.2	2.0	0.6	0.4	0.1	0.0	0.0	0.0	0.0
9 plants/s	11.8	3.1	1.1	0.1	0.2	0.0	0.1	0.0	0.0	0.0
Seed shape										
1-cut	13.6	5.6	3.7	1.9	1.2	1.0	0.7	0.1	0.4	0.4
2-cut	13.5	5.6	2.8	1.5	0.3	0.3	0.2	0.0	0.0	0.0
3-cut	9.8	4.7	1.3	0.8	0.5	0.1	0.8	0.0	0.0	0.0
Seed size										
45 g	12.7	3.7	1.9	0.6	0.2	0.1	0.2	0.0	0.0	0.0
60 g	11.8	6.8	3.3	2.2	1.1	0.8	0.9	0.1	0.2	0.3

* Average for 5 replications
(minimum of 100 metering events for each replication)

Table 3.3 Distribution of consecutive metering errors for whole seed.

Percent of total metering events which were unsuccessful *										
	Consecutive metering errors									
	1	2	3	4	5	6	7	8	9	10
Metering rate										
3 plants/s	11.1	12.5	9.0	9.0	4.3	5.0	0.8	1.1	1.1	0.0
6 plants/s	14.9	7.1	5.4	2.7	0.6	0.0	0.0	0.0	0.0	0.0
9 plants/s	10.7	2.6	1.5	0.3	0.2	0.2	0.0	0.0	0.0	0.0

* Average for 5 replications
(minimum of 100 metering events for ~~each~~ replication)

interaction proved to be insignificant. The lack of significance of the seed shape and size interaction, when compared to the high levels of significance shown from other sources of experimental error, suggested that seed shape and size affect metering performance in an independent manner. The only second-order interaction (metering rate x shape x size) was significant at the p = 5 percent level. Metering rate for whole seed was established to be significant at the p = 1 percent level as summarized in the ANOVA in Table 3.5.

Metering errors tended to decrease as the number of cut surfaces increased, or as seed pieces became more blocky. This trend is illustrated in Figure 3.6 and may be due to a greater probability of a flat surface presenting itself simultaneously to both picks at an angle normal to the penetrating force. Seed pieces with rounded surfaces (eg. 1-cut pieces) laying near the picker wheel tend to project the seed's center of gravity away from the pick's path, and thus decreases the probability of a successful metering event. The possibility of only one pick penetrating potato flesh also is enhanced. Consequently some seeds became disengaged before reaching the planting tube.

An in-depth analysis of seed shape effects on metering performance revealed a distribution of consecutive metering errors favoring the performance of

Table 3.4 Analysis of variance for cut seed metering trials.

Source of variation	df	SS	MS	F
Blocks	r-1 = 4	7,353	1,838	57.1 **
A = Shape	a-1 = 2	3,268	1,634	50.5 **
B = Metering rate	b-1 = 2	4,865	2,433	75.5 **
C = Size	c-1 = 1	905	905	28.1 **
AB	(a-1)(b-1) = 4	2,192	548	17.0 **
AC	(a-1)(c-1) = 2	70	35	1.1
BC	(b-1)(c-1) = 2	1,094	547	17.0 **
ABC	(a-1)(b-1)(c-1) = 4	342	86	2.7 *
Error	(r-1)(abc-1) = 68	2,399	32	
Total	89	22,488		

** significant at p = 0.01
 * significant at p = 0.05

Table 3.5 Analysis of variance for whole seed metering trials

Source of variation	df	SS	MS	F
Among metering rates	t-1 = 2	4,313	2,157	216 **
Within metering rates	t(r-1) = 12	117	10	
Total	14	4,430		

** significant at p = 0.01

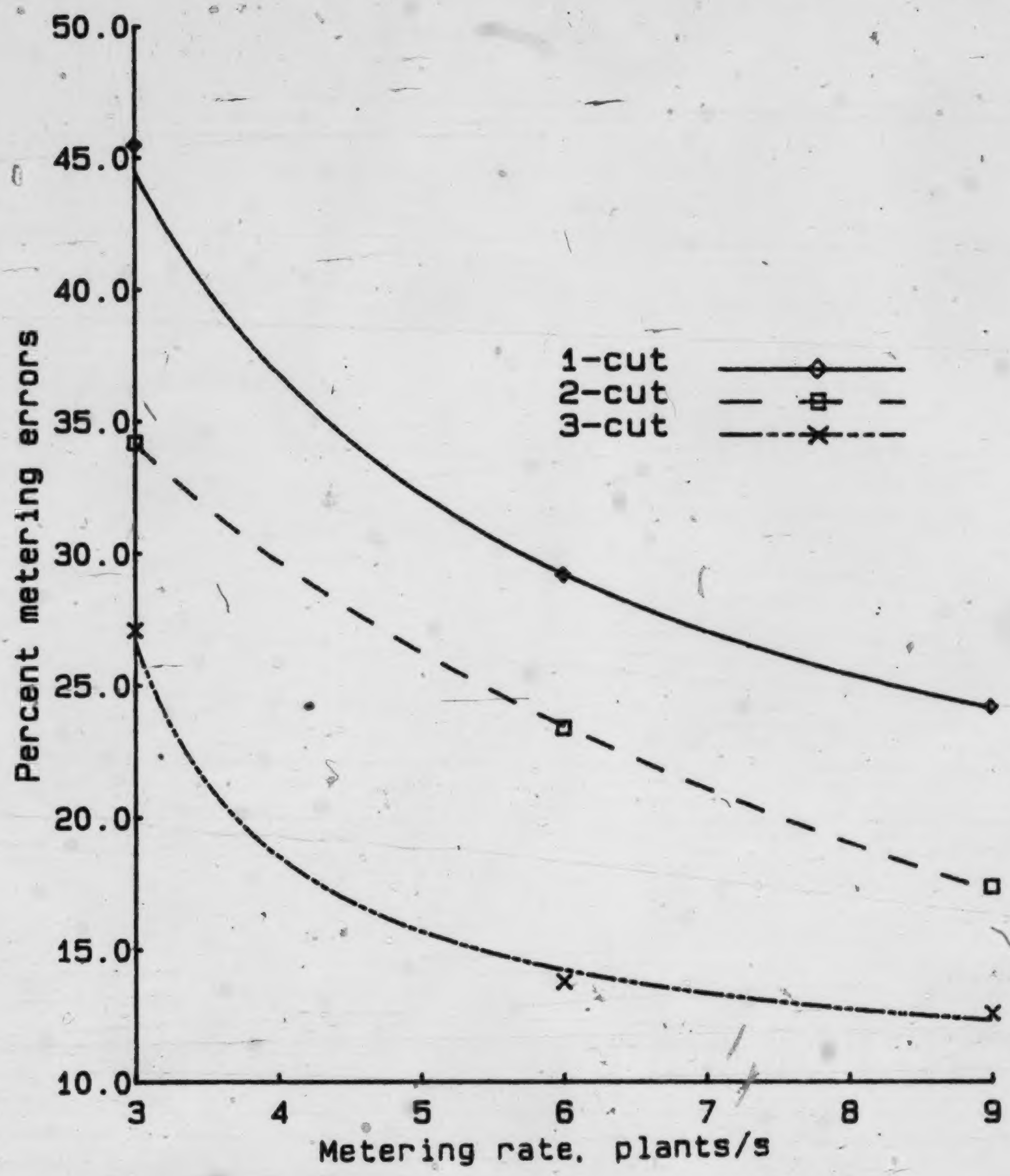

Figure 3.6 Seed shape effect on metering performance

3-cut pieces (Figure 3.7). The frequency of consecutive metering errors was consistently lower for 3-cut pieces when compared to 2-cut and 1-cut pieces.

3.4.2.2 Relation of Seed Size to Metering Errors

Results indicate the larger (60 g) seed performed poorly at 3 plants/s when compared to the 45 g seed. However, metering errors for each size were comparable above metering rates of 6 plants/s (Figure 3.8). The explanation for this trend is, simply, that larger and heavier seed tends to fall off the picks easier than smaller and lighter seed, especially when pick penetration is shallow. Poor performance of larger and heavier seed is partially due to an unbalanced distribution of seed weight on the picks which may lead to premature seed release.

Figure 3.9 presents the distribution of consecutive metering errors for both 45 g and 60 g seed. Aside from the one consecutive metering error category, 45 g pieces had fewer continuous misses.

3.4.2.3 Relation of Metering Rate to Metering Errors

Metering rate had the most distinct influence on metering performance. On average, cut seed metering errors were 35, 22, and 18 percent for planting rates of 3, 6, and 9 plants/s respectively. Figures 3.6, 3.8, and 3.9 illustrate the correlation between higher metering rates and fewer metering errors. Faster picker

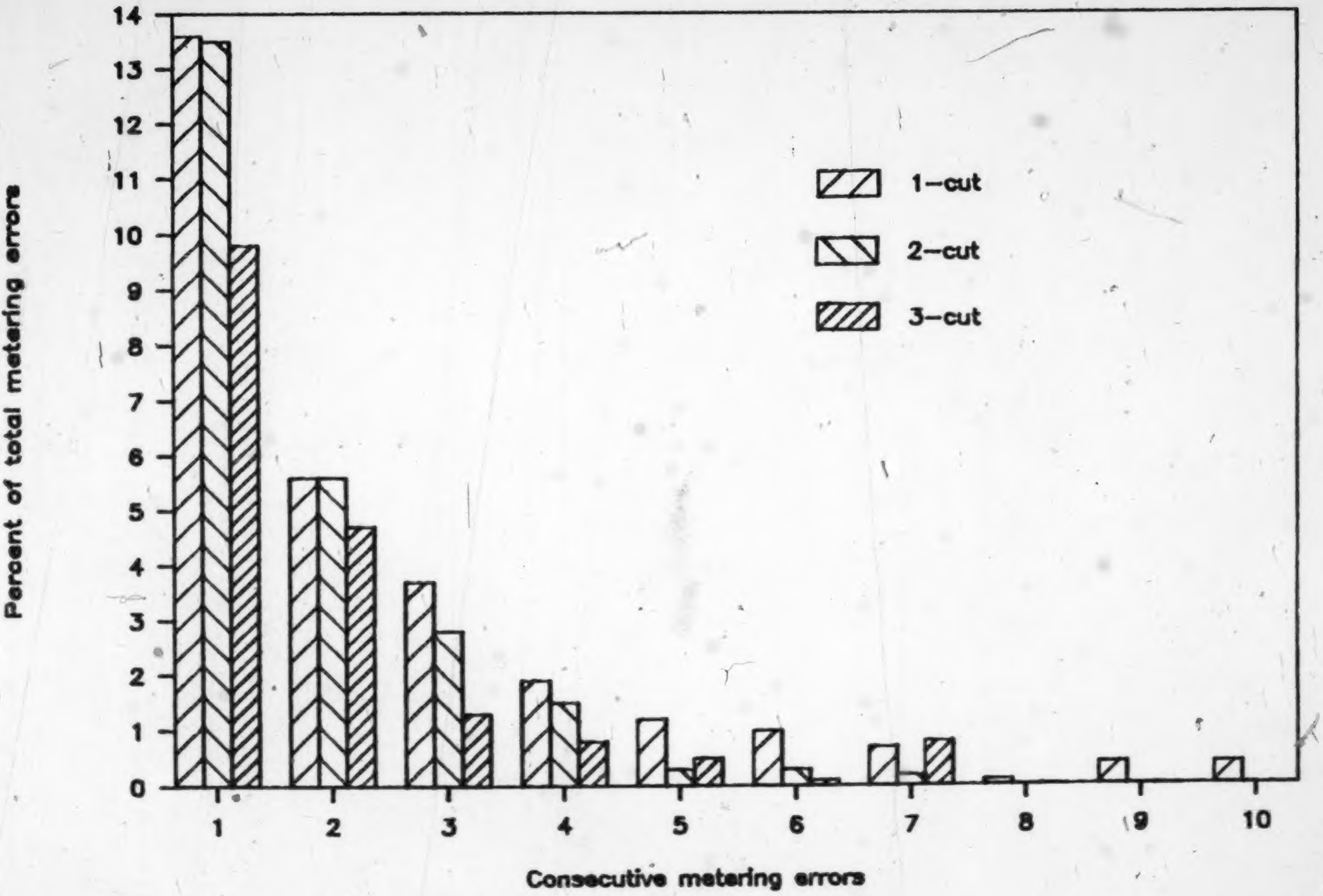

Figure 3.7 Consecutive metering error distribution for seed shape

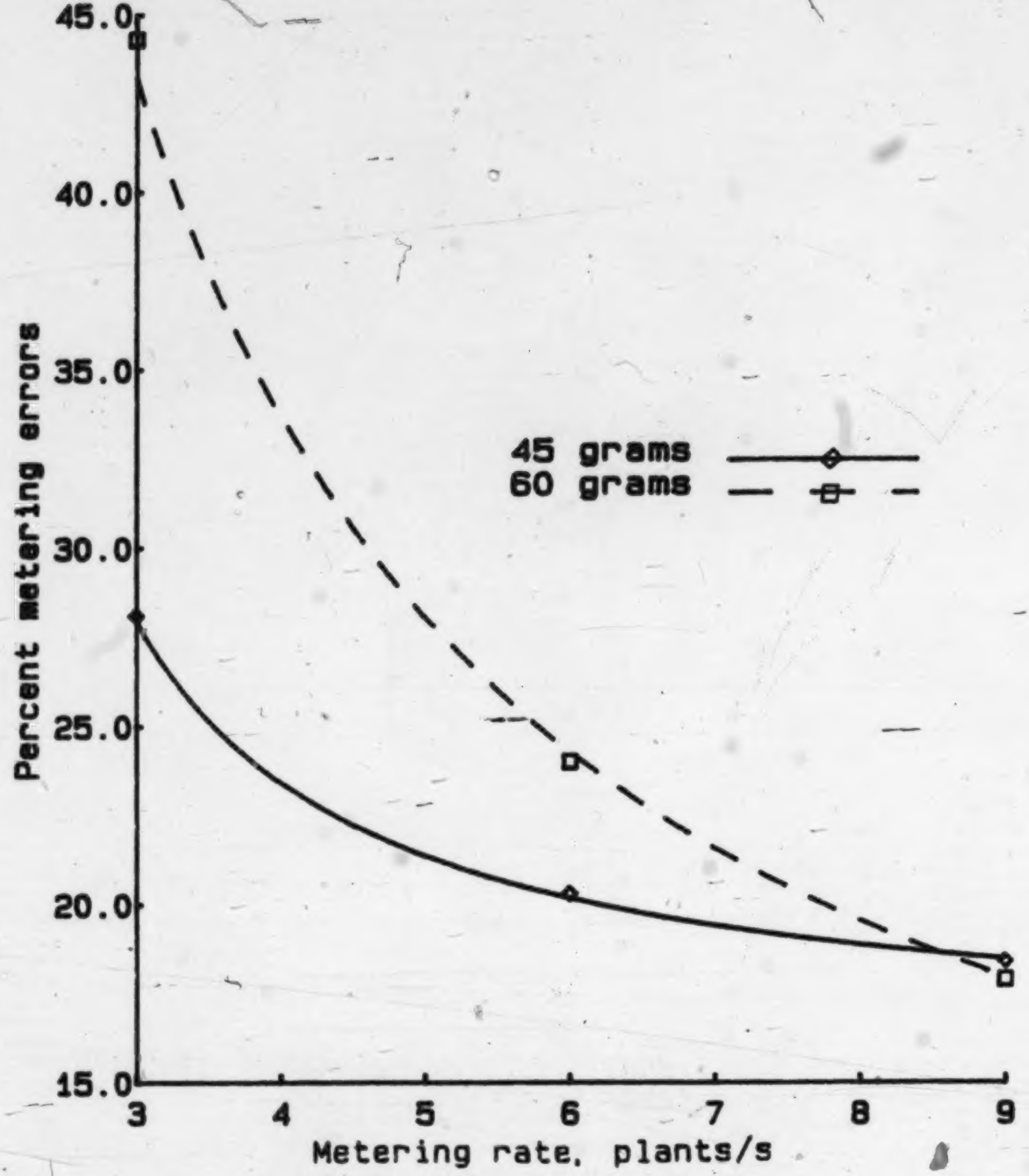

Figure 3.8 Seed size effect on metering performance

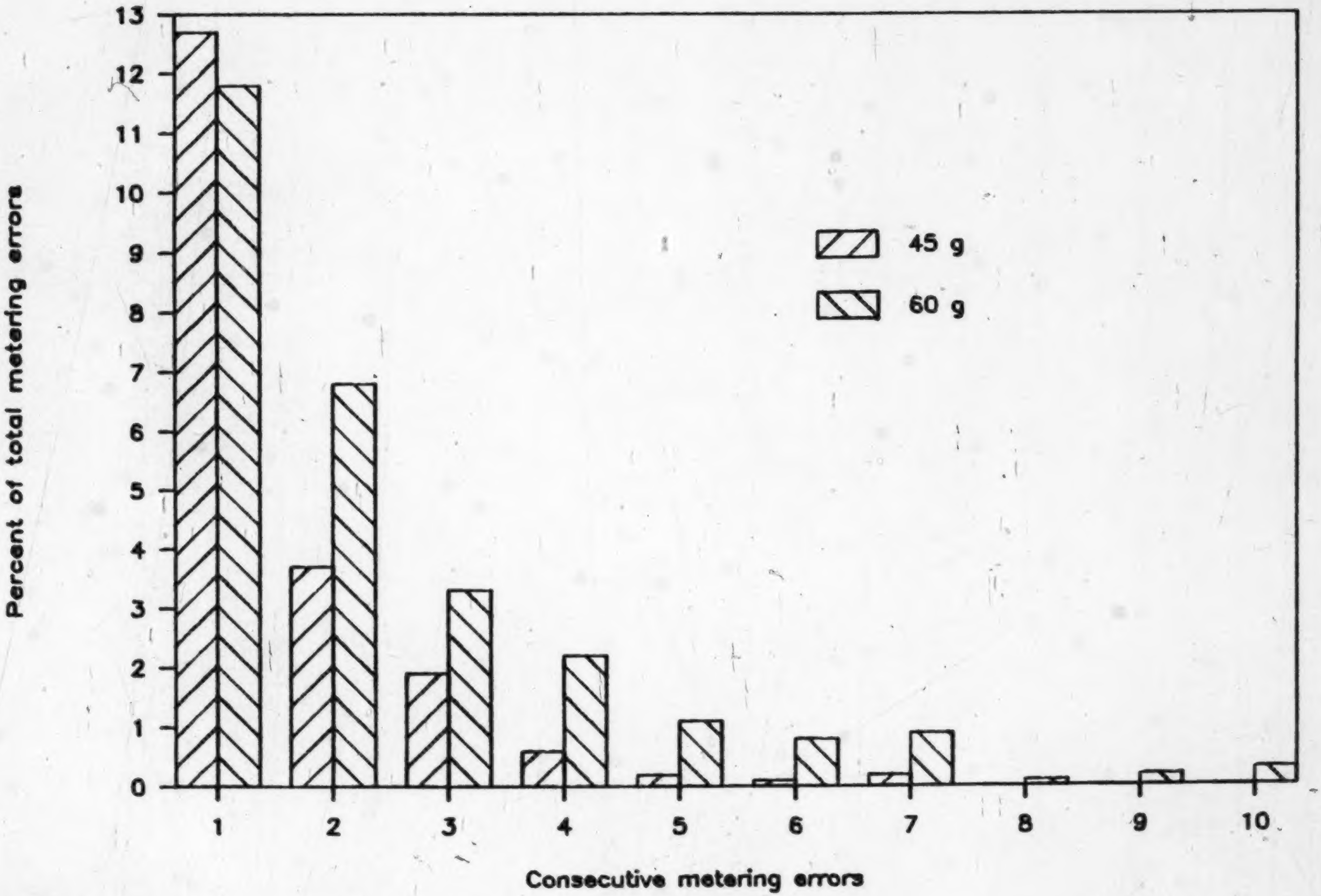

Figure 3.9 Consecutive metering error distribution for seed size

wheel velocity increased the penetration force exerted by the picks and resulted in a deeper and more secure engagement of the seed piece. The consecutive metering error distribution for all cut seed trials is summarized in Figure 3.10 and clearly shows a consistent improvement in metering performance as metering rate increased.

The analysis of variance for whole seed trials presented in Table 3.5 indicates that the metering rate is a significant factor for metering performance. Whole seed metering errors decreased as metering rate increased. However, metering rate effects are more pronounced for whole seed *versus* cut seed (Figure 3.11). The exceptionally high value of 55.4 percent metering errors at 3 plants/s was caused by insufficient penetration of the relatively heavy potatoes (50 to 100 g) which led to many premature releases. A similar situation was observed on high speed film by Sieczka et al (1986). This appears to support the significance of the metering rate x size interaction for cut seed.

The consecutive miss distribution for whole seed in Figure 3.12 provides a more detailed assessment of whole seed performance.

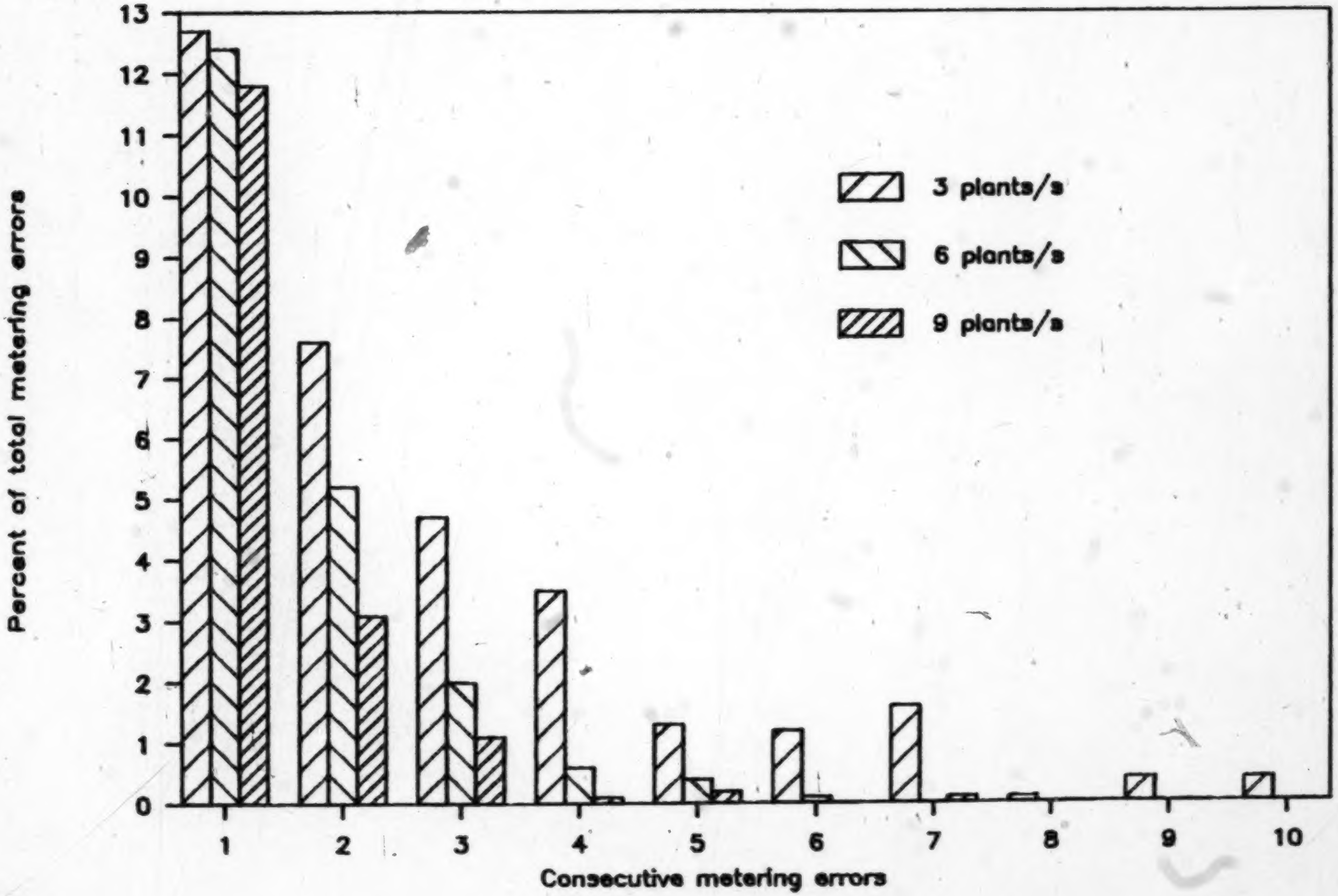

Figure 3.10 Metering rate effect on consecutive metering error distribution for cut seed

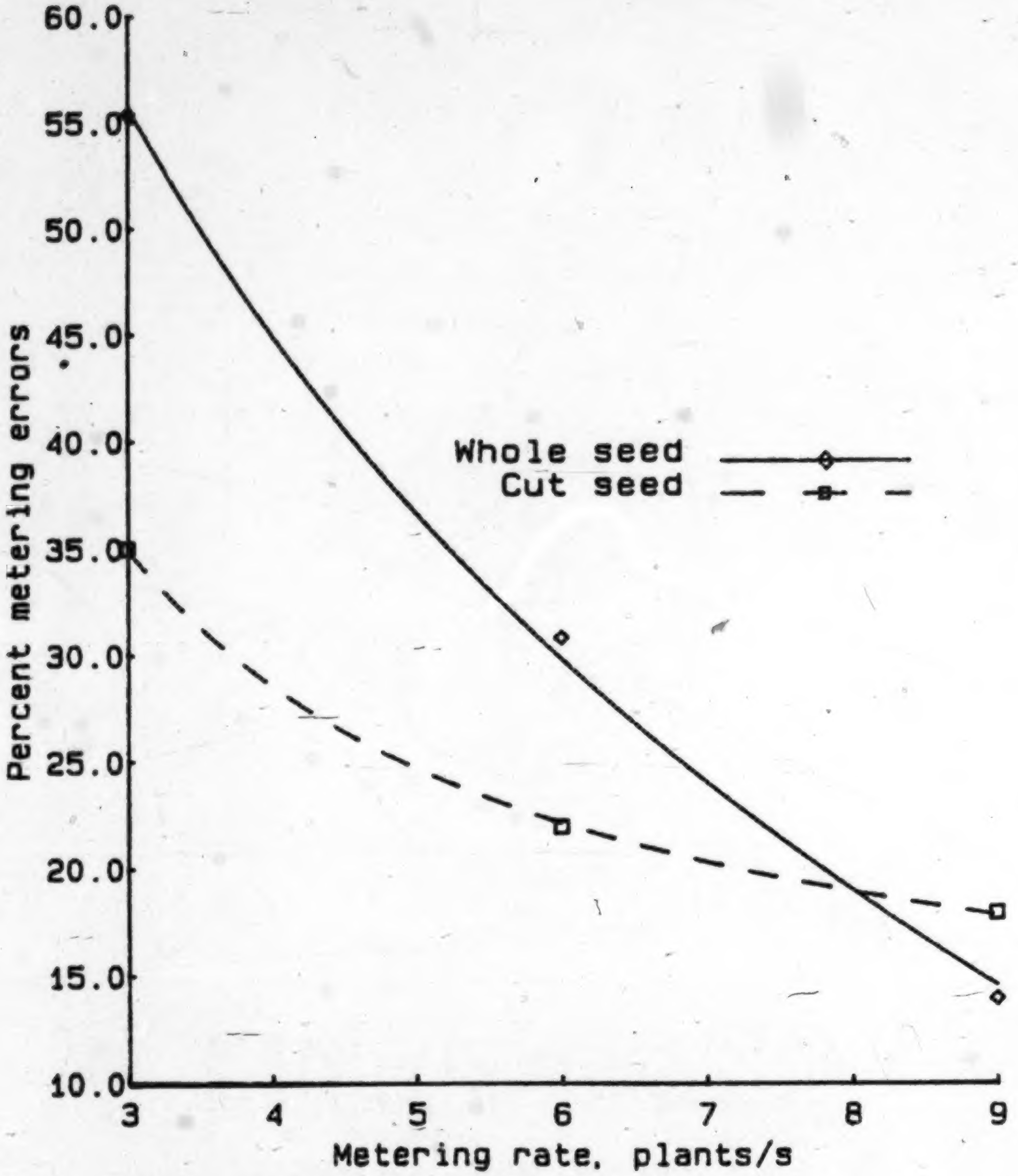

Figure 3.11 Metering performance of whole verses cut seed

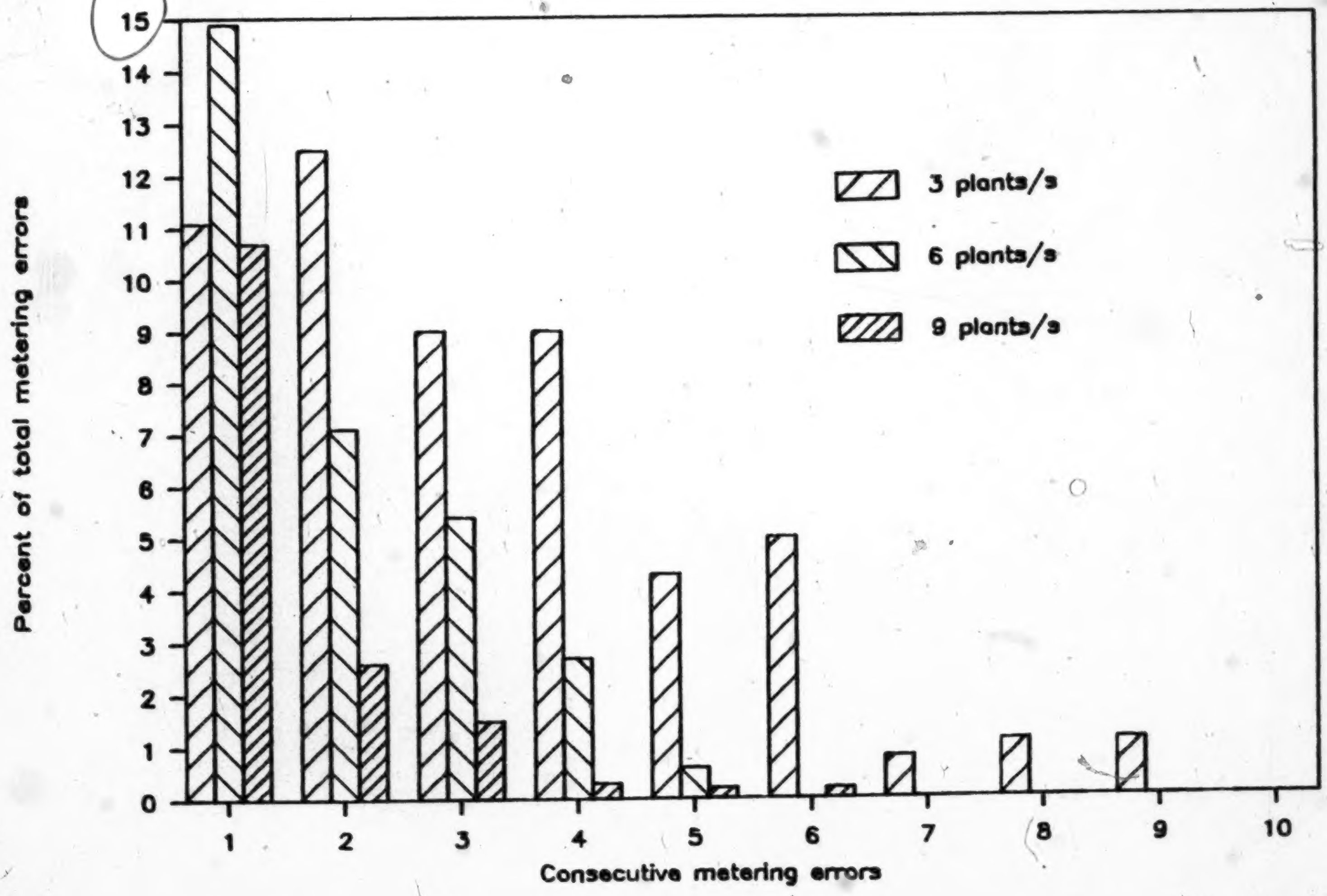

Figure 3.12 Metering rate effect on consecutive metering error distribution for whole seed

4. POTATO PLANTER MONITOR

4.1 Introduction

Although growers realize that potato seed attributes and planter operating conditions affect planter performance, a reliable means of accurately assessing performance in the field does not seem to exist. Today, operators are still seen riding on the planter to ensure adequate performance. Although this raises safety concerns, operator supervision provides a means of detecting mechanical problems as they occur and enables visual performance assessment. One-person planting operations have used elaborate mirror systems to monitor performance with some success. However, direct awareness of cup and pick-type planter performance could be possible through a monitoring system. The planter monitoring process, illustrated in Figure 4.1, encourages growers and planter operators to improve planter performance by avoiding undesirable interactions between seed potatoes, the planter and operating conditions.

4.1.1 Objective

The objective of this chapter is to discuss the design and development of a potato planter monitoring system capable of providing performance feedback to operators.

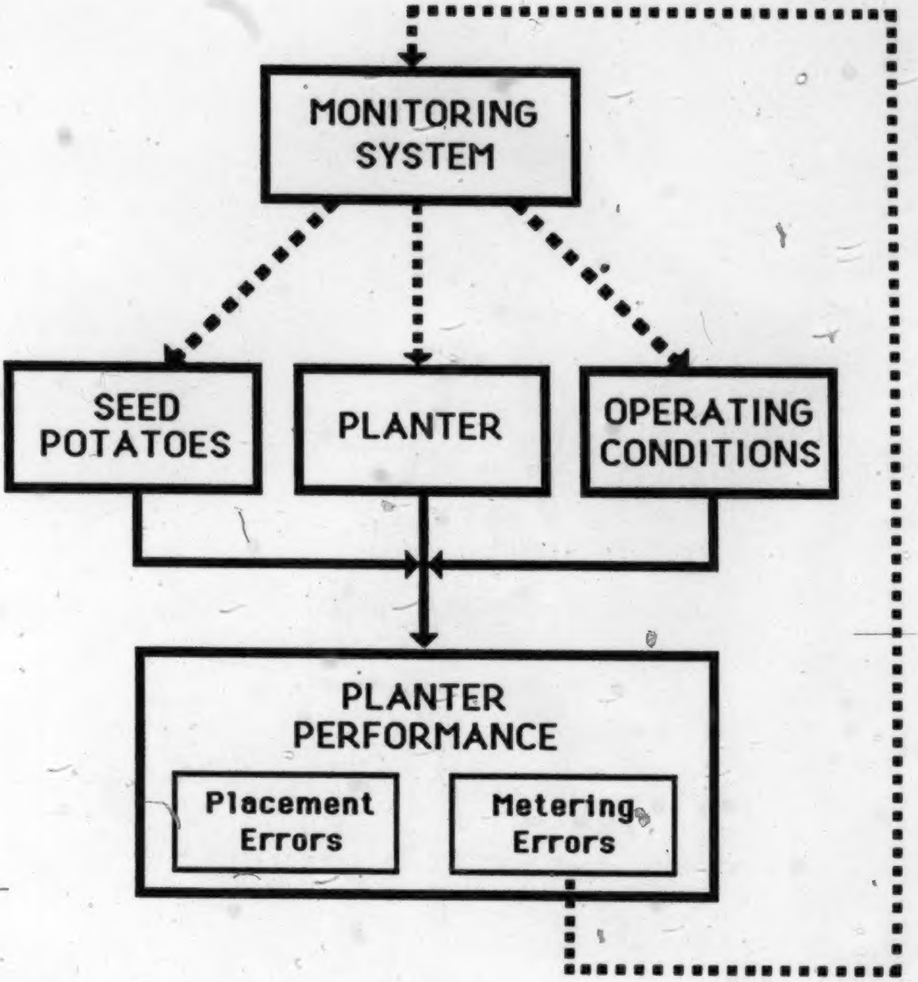
MONITORING SYSTEM
SEED POTATOES
PLANTER
OPERATING CONDITIONS
PLANTER PERFORMANCE
Placement Errors
Metering Errors

Figure 4.1 The potato planter monitoring process

4.1.2 Design Criteria

Improving potato planter performance has been a priority in the potato machinery industry for the last fifteen years. From the discussion on the effect of population density in section 2.2.1, the avoidance of consecutive metering errors caused, either by a disruption of seed flow, or an incompatibility within the planting operation, is more important than the accuracy of seed placement.

Gauthier (1985) assessed requirements of intelligent field management information systems in two main categories: functional and informational requirements. Functional requirements included: maintaining data consistency and validity, ability to handle a variety of information sources and transmission methods, the ability to adapt to the surrounding environment, and provision for displaying the information contained in memory. Information requirements were subdivided into attributive and historic categories. Field management information systems also need a means of altering system attributes in order to maintain system flexibility.

An accurate information base can be maintained only so long as correct information is received from the sensors. Indication of sensor malfunction alleviates the likelihood of erroneous information that may lead to performance degradation, equipment damage or safety hazards. Tylee (1986) presented a model-based approach to instrument failure detection.

Considering the requirements and limitations of the potato planting process, the following monitor design criteria were put forth:

1. Immediate visual indication of consecutive metering errors for each row.
2. Intermittent visual display of planter performance statistics for each row.
3. Visual indication of drive train and sensor malfunction.
4. Audio indication of defective metering elements.
5. Compatibility with cup and pick-type planters.
6. Efficient operation under field conditions.

The monitoring system developed from these criteria was tested under simulated conditions in the laboratory. Unfortunately a field prototype was not tested. However section 4.6 outlines some design details worth considering should further monitor development take place.

4.2 Hardware

The potato planter monitor's circuit consists of three distinct parts: the microprocessor board, the sensor system, and the display unit. For field applications, each planter row has a sensor system mounted in the appropriate position with shielded power and input/output wires leading to a sensor junction module on the planter. Details of sensor system operation, as discussed in section 3.3.2, should be understood in order to appreciate the following discussion.

Figure 4.2 illustrates how monitoring system modules function in relation to one another. The monitor module in the tractor cab contains the microprocessor board, display unit and input devices used to select the monitor's mode of operation. Sensor signals, from each row, are relayed through the junction module to the monitor module. The tractor's twelve volt electrical system provides an independent power supply to the monitor module and the junction module.

Four sources of performance feedback are available from the display unit (Figure 4.3). Each vertical array of LEDs corresponds to one of the planter's metering mechanisms. The four yellow metering LEDs operate in a up-down fashion to indicate the number of consecutive misses that have occurred in the last four metering events. The top and bottom status LEDs are red and indicate potato sensor and metering event sensor malfunction respectively. The bottom status LED also serves as a drive train malfunction indicator. A green row-select LED was positioned between the malfunction indicators to indicate the row corresponding to the statistics on the alphanumeric display. One of five performance statistics can be displayed on the single line, sixteen character liquid crystal display unit (LCD). The buzzer, mounted on the back of the display unit, serves to indicate a defective metering element.

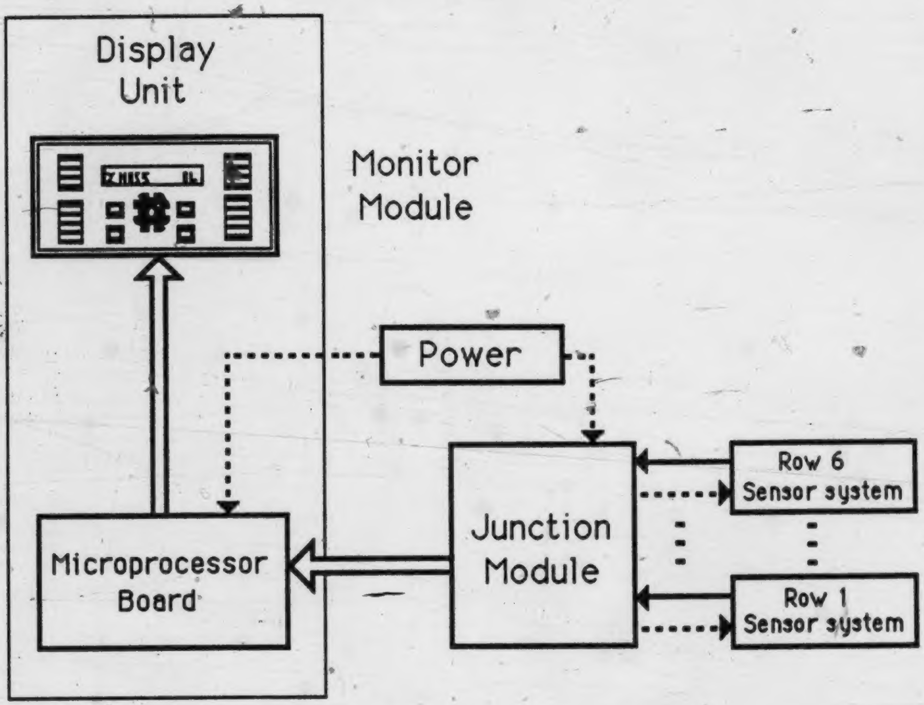
Display
Unit
Monitor
Module
Power
Microprocessor
Board
Junction
Module
Row 6
Sensor system
Row 1
Sensor system

Figure 4.2 Block diagram for potato planter monitor modules

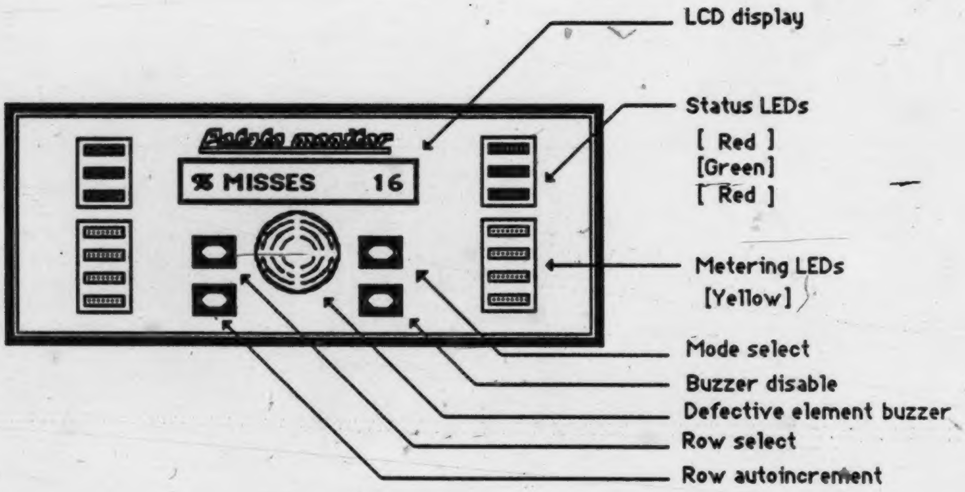
% MISSES 16
LCD display
Status LEDs
[Red]
[Green]
[Red]
Metering LEDs
[Yellow]
Mode select
Buzzer disable
Defective element buzzer
Row select
Row autoincrement

Figure 4.3 Monitor display unit

4.2.1 Circuit Description

A composite view of hardware function is illustrated in the block diagram presented in Figure 4.4. A complete list of the monitor's electronic components is found in Appendix C. Operating characteristics of the monitor's integrated circuits can be found in Motorola Semiconductor Products Inc. reference manuals.

4.2.1.1 Microprocessor Board

At the heart of the monitoring system is a M6809 microprocessor with 2k of read only memory (ROM) and 2k of random access memory (RAM). The M6809 is an eight bit microprocessor with a 16-bit address bus and an eight-bit data bus . Monitor circuit development took place on a perforated circuit board that was mounted on an aluminum frame. All components were set in sockets to facilitate component interchange. The wire wrap technique was used to make the required connections between socket pins.

Incoming 5.0 V (Vcc) and ground (Gnd) wires were attached to the Vcc or Gnd bars running the length of the underside of the microprocessor board. A 150 uF capacitor was positioned between the incoming end of the Vcc and Gnd bars to reduce power supply fluctuations. Decoupling capacitors (10 uF) were positioned between the Vcc and Gnd bars at 25 mm intervals. This provided a steady 5 v potential across the processor board.

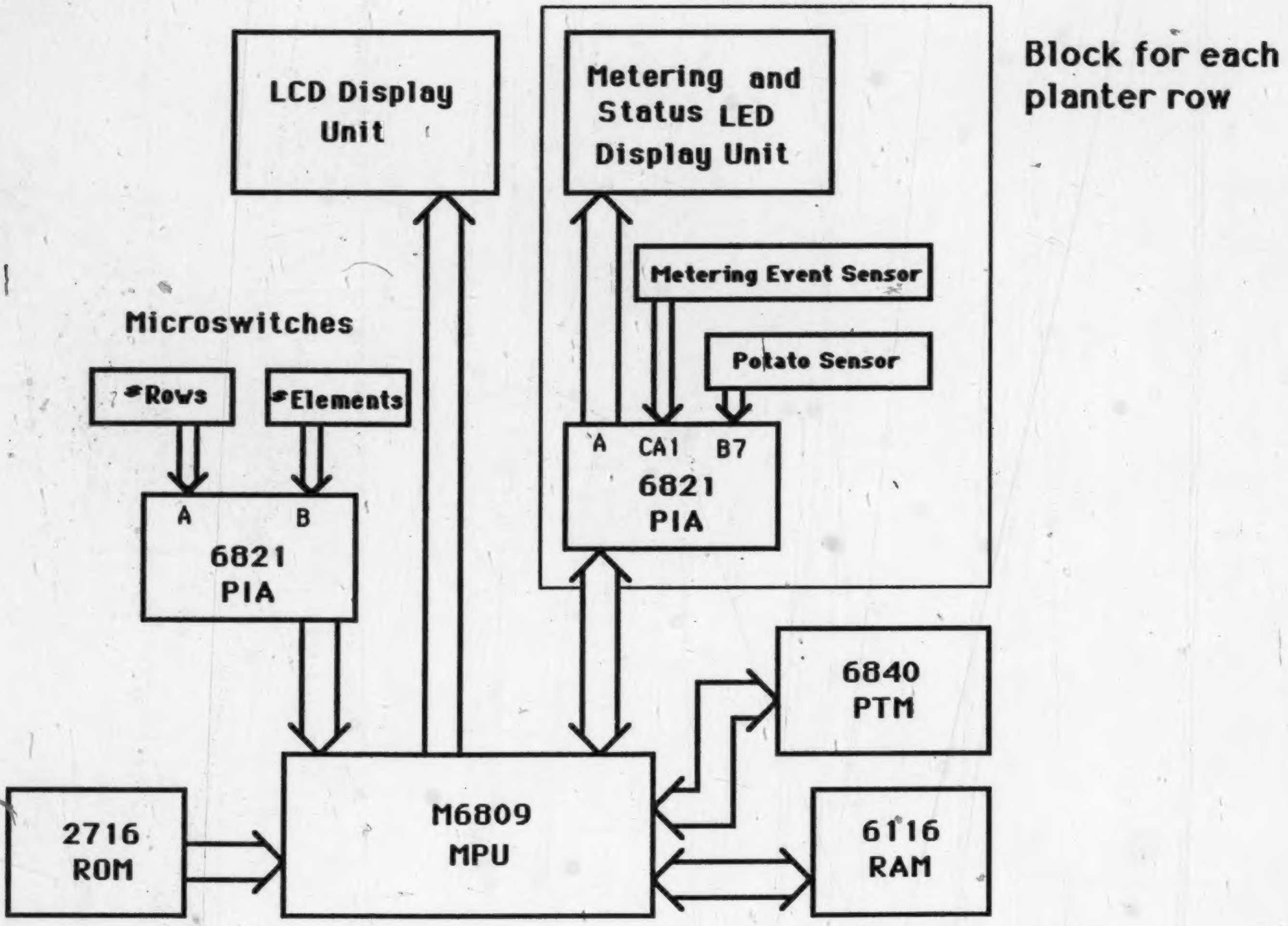
LCD Display Unit
Metering and Status LED Display Unit
Block for each planter row
Metering Event Sensor
Potato Sensor
Microswitches
#Rows
#Elements
A
B
6821 PIA
A
CA1
B7
6821 PIA
6840 PTM
2716 ROM
M6809 MPU
6116 RAM

Figure 4.4 Potato planter monitor block diagram

A single 3.58 MHz crystal connected to ground via two 27 pF capacitors produced the external clock signal. The crystal was connected to the EXTAL and XTAL pins on the M6809 microprocessor in order to activate the the M6809's internal oscillator at four times the crystal frequency (14.31 MHz). Circuit details are given in Appendix D1.

Several pins of the M6809 were unused. Consequently their voltage potential was set to Vcc through 4.7 kΩ pull-up resistors to ensure proper microprocessor function. The nonactive control pins were the Fast Interrupt Request (FIRQ*), Halt (HALT*), Direct Memory Access/Break (DMA/BREQ*), and Memory Ready (MRDY). Refer to Appendix D1 for microprocessor circuit details.

A reset circuit (Appendix D1) was implemented to eliminate multiple pulses due to contact bounce. A normally open momentary push button switch was connected via two cascaded inverters (7414 Hex Schmitt-Trigger inverter) to the reset pin on the M6809. A pull up resistor of 10 kΩ was connected to the inverter input thus yielding a normally high voltage. When the reset button was depressed, the voltage potential on the reset pin was drawn to ground and the microprocessor's reset instructions were executed.

Buffers were installed on the data, address and control lines to prevent loading conditions. Data lines were buffered with an octal bus transciever (74LS245), and address and control lines were buffered with octal buffers/line drivers/line receivers (74LS244). The buffered control lines on the M6809 were the E and Q clock signals, bus status (BS), bus available (BA), and read write (R/W*) lines. The E* pin on the data line buffer was grounded to permit continuous data line access. The DIR pin on the data line buffer was connected to the buffered R/W* line to control the direction of data transfer. The E1* and E2* pins on the address and control line buffers were grounded to ensure continuous access to these lines. Appendix D1 contains details for circuit buffers.

Buffered address lines A12 to A15 were decoded by a 74LS154 four to sixteen line decoder demultiplexer. The decoder operated on the E clock cycle through a NAND gate (7400 two-input positive NAND gate). Decoder output provided sixteen select lines (SEL 0 - SEL F) which effectively divided the 64k of addressable space into sixteen 4k blocks. Refer to Appendix D2 for the address decoding circuit diagram. All addresses in the following discussion are in hexidecimal notation.

The 2716 erasable programmable read only memory (EPROM) was connected to operate in the addressable range of F800 to FFFF. To address this memory block, further decoding was necessary and was accomplished by comparing the SEL F line and the address line A11 with a NAND gate. The output from the NAND was connected to the output enable pin (G*) on the EPROM. Thus the EPROM was selected when the address on the address bus fell between F800 and FFFF. An additional EPROM address space (F000-F7FF) was provided for future program expansion. Address decoding for this EPROM was accomplished by comparing the SEL F* and A11* lines with a NAND gate. The resulting signal was fed to the G* pin of the second EPROM. Hence, the two EPROMs were contained in a continuous address space. Refer to Appendix D3 for the EPROM circuit diagram.

A 6116, 2048 word by eight bit, high speed, static CMOS RAM, provided 2k of memory. The 6116 chip has a low power requirement, fast access time, is TTL compatible, and is compact in design. The RAM's address range spanned memory locations D000-D7FF. Address lines A0-A6 were decoded to select one of the rows in the RAM's internal matrix while address lines A7-A10 were used to select the matrix columns. A by a high to low transition on SEL D line provided the 6116 RAM's chip select signal. Data transfer to or from RAM memory, via the buffered data bus, was controlled by the read/write line. Refer to Appendix D4 for the RAM circuit diagram.

Two 6850 asynchronous communications interface adapters (ACIAs) were connected to the monitoring system for the purpose of serial communication with a microcomputer. The host ACIA was located in the memory space of E008 to E009 while the terminal ACIA occupied addresses E00A to E00B. Address decoding was based on the SEL E signal and address lines A0 to A3. The data bus was connected to both of the ACIAs as was the R/W* line and the interrupt request (IRQ) line. Unused pins Vss, DCD* and CTS* were grounded. External access to the ACIAs was provided through a D-9 connector. Appendix D5 illustrates the ACIA circuits. Although serial communication is not supported by current system software, the necessary hardware is in place and could be useful for downloading the distribution of consecutive misses for each row to a microcomputer. This would facilitate a detailed assessement of planter performance in terms of established planting density relationships.

Peripheral interface adapters (PIAs) were used to provide a means for parallel communication between external devices and the microprocessor system. A sensor system and a corresponding vertical array of seven light emitting diodes (LEDs) were associated with each row PIA. The monitoring system accomodates planters with two to six rows and therefore row PIAs are labeled PIA1 to PIA6. An additional PIA was needed to read the microswitch values that are used, by the operator, to set the number of planter rows and the number of metering elements for each row. Row PIAs were assigned addresses 1000, 2000, ...,6000 and the microswitch PIA occupied the address 7000. The corresponding select lines, SEL 1 to SEL 7, were connected to the respective PIA's CS2* pin. Address decoding was completed by connecting the address lines A0 and A1 to RS0 and RS1 respectively. The unused chip select pins, CS0 and CS1 were connected directly to Vcc. Data bus connection facilitated the transfer of information from the sensors and to the display LEDs. Refer to Appendix D6 for the row PIA circuit diagram, and Appendix D7 for the microswitch PIA circuit diagram.

The MC6840 Programmable Timer Module (PTM) provides the microprocessor system with three timers. Since the PTM has data input and output requirements, the eight data bus lines were connected to the PTM. The PTM occupied memory locations E000-E007. This PTM was selected by the SEL E line which was connected to the PTM's CS0* pin. Address lines A0, A1, A2, and the inverted A3 line were connected to lines RS0, RS1, RS2 and CS1 respectively, to complete addressing requirements. Control lines R/W*, E, RES* and IRQ* were connected to their corresponding PTM pins. Two of the three on-board timers (timers two and three) were cascaded to give a five-second timeout signal. Timer one assumed an internal clock function. The periodic five-second timeout initiated a metering statistic update and refreshed the LCD display. Appendix D8 contains details of the PTM circuit.

4.2.1.2 Input Devices

Two eight bit microswitches were used, one to indicate the number of planter rows, the other to set the number of metering elements per row. Port A of the microswitch PIA corresponded to the number of rows and port B was used to indicate the number of metering elements per row. Pins on the 'on' side of the microswitch were connected to Vcc. Pins on the 'off' side of the microswitch were connected through a 10 kΩ resistor, to ground before being tied to either A or B port pins on the microswitch PIA. Refer to Appendix D7 for circuit details.

The dual-sensor, event-triggered system discussed under section 3.3.2 was used to determine metering status. The output signal from the Hall effect switch (3019T, Sprague), or metering event sensor, was passed through two inverters to obtain a TTL-compatible logic signal (Appendix D10). This signal was in turn fed to the CA1 pin of the PIA corresponding to the interrupting sensor. High to low transitions on the CA1 pin signalled a metering event and interrupted the microprocessor to indicate the need for a metering update.

A photoscanner (MCS-651 series, Warner Electric, Marengo, IL.) was used as the potato sensor (Appendix D9) and determined the metering status. The photoscanner used a modulated infrared light beam that was immune to external sources of light and had an operational range of 50 cm. Both the photoscanner transmitter and receiver had a 5 V power supply requirement. The output from pin 1 of the receiver amplifier was pulled up with a 4.7 kΩ resistor and fed through a NAND gate acting as an inverter. The resulting signal was passed to pin 7 of port A on the row PIA corresponding to the potato sensor. Thus, a broken beam produced 5.0 V (logic 1) and an intact beam resulted in 0.0 V (logic 0).

Five operator input devices were included in the operating system. Three momentary closed push button switches were used for the reset, mode change, and row change functions. The mode change and row change circuits are illustrated in Appendix D11 and D12 respectively. Two toggle switches were used, one for the row autoincrement function and the other for the buzzer disable function.

4.2.1.3 Output Devices

Three types of output device were used in the monitor module: an alphanumeric display unit, vertical arrays of seven LEDs to indicate metering and status information, and a buzzer. These devices are illustrated on the monitor display unit in Figure 4.3.

A one line by sixteen character, top view, five by seven dot matrix alphanumeric liquid crystal display

(LCD) module (Printed Circuits International PCIM 200) was used to display messages and performance statistics. A performance statistic corresponding to one of five modes of operation was displayed constantly when the planter was in operation. For example, a typical display would be '% MISSES 16', where '%MISSES' is the descriptor and '16' represents the performance statistic. The LCD display module employed low power CMOS circuitry and was connected directly to the M6809 data bus. Sixty-four commonly-used ASCII characters formed the character set and could be passed directly from the data bus through the module's sixteen character buffer and onto the display line. The display was automatically refreshed, temperature compensated and had fully adjustable contrast. Control instructions allowed the display to be operated in various modes. The module required thirteen pin connections, eight of which were data lines. Other lines were Vcc, ground, and the CS* pin which was connected to the SEL 0 pin of the address decoder, placing the device at the address 0000. The Memory Write pin (MWR*) was connected to the R/W* line of the M6809. The remaining pin, memory read (MWR*), was connected to Vcc in order to deactivate the memory read function. Refer to Appendix D13 for the display circuit diagram.

The metering and status LEDs were connected to the B side of row PIAs through a high-voltage open-collector output buffer/line driver (7407N). In order to illuminate a LED, the driver had to be supplied with a low voltage from PIA data port pins. Output lines 0 through 3 on the PIA were connected to the four yellow metering LEDs to indicate the number of current consecutive metering errors. Output lines 4 and 6 were connected to the red LEDs which were used to indicate a malfunctioning metering event sensor or potato sensor. The middle status LED was green and was termed the row select LED. Performance statistics on the LCD corresponded to the row with the illuminated row select LED. The current flowing through the LEDs was limited by 47Ω resistors. This provided adequate illumination while ensuring LED longevity. LED anodes were connected to the Vcc and the cathodes were connected to the driver which provided the ground needed to turn the LEDs on. All LEDs were rectangular in shape and were visible in an outdoor environment.

The defective element indicator was a 5-volt buzzer (Radio Shack 273-068). The buzzer produced a sound loud enough for the operator of a tractor to hear. The buzzer was connected through output line 7 on the B side of the row PIAs and was driven by an open collector line driver identical to the ones used for the LED circuits. Thus the buzzer was activated when the PIA output was low.

4.2.1.4 Power Supply

Although a 5.0 V switching regulator was considered for field operating conditions, laboratory testing was done with a Hewlett Packard 6236B power supply unit set to 5.0 V.

4.3 Software

Program software provided the 6809 microprocessor with instructions for the monitoring algorithm in an effective and well-defined manner.

The potato planter monitor program was written in Motorola 6809 Assembler Language. All programs associated with this project were assembled using the UNSP:M6809ASM assembler implemented on the MTS system at the University of Alberta. The resulting object code was downloaded to EPROMS using a Unipak System 19 Data I/O unit. Program and hardware debugging were done with the assistance of a Hewlett Packard model 1615A logic analyzer and the potato planter simulation unit. The assembled monitor program, as listed in Appendix E, occupies 1.8 k of ROM and is designed to function with two to six sets of sensors.

4.3.1 Memory Structure

Memory structure can be thought of as the ordered arrangement of program and memory addresses. The six identifiable divisions in the potato monitor's memory structure are: device addresses (Appendix F1), program addresses in ROM (Appendix F2), system vectors in ROM (Appendix F3), ROM data addresses (Appendix F4), program variable addresses in RAM (Appendix F5) and RAM data blocks for each row (Appendix F6). Program-variable address assignments and descriptions are on lines 13 to 89 of the program listing in Appendix E. Alphabetic listing of variable names, together with the line numbers they were referenced on, are listed in the cross reference section of Appendix E (assembler page numbers 17-19).

Due to identical program and memory requirements for each row being monitored, a structured, top-down programming approach was employed and relative addressing was used extensively. Base addresses for row PIAs were arranged at address intervals of 1000. Similarly row data blocks in RAM were arranged in address intervals of 0100. This allowed one block of program code to process the input and output requirements for two to six rows and made the iterative performance statistic calculations more efficient.

System service routine addresses for the interrupt request function (IRQ), non maskable interrupt (NMI), and reset (RESET) were assigned to ROM addresses FFF0-FFFF. If the pins corresponding to these microprocessor functions recognize a transition in logic voltage, the processor is diverted to the appropriate internal instructions before program flow is directed to the function's address.

4.3.2 Description

The program listing in Appendix E is commented extensively and flow charts are utilized in the following discussion as an aid to understanding program logic. For general questions related to 6809 Assembly language programming, the reader is referred to Leventhal (1981).

Upon a reset condition, the monitoring system executes an initialization sequence and then simply waits for interrupt signals (Figure 4.5). When interrupts occur, one of four options are pursued: a metering update, a statistics and display update, a mode change to alter the type of statistic on display, or a row change to alter the row currently displayed on the LCD. A fifth mode for displaying the distribution of consecutive metering errors was only partially implemented and thus remains inoperable. The IRQ service routine is used to identify system needs and directs program flow. The general overview of the IRQ service routine presented in Figure 4.6 illustrates the interrupt-driven nature of the monitoring program.

4.3.2.1 Initialization

The flow chart for the initialization routine is set out in Figure 4.7. Initialization of the LCD display involved setting parameters within the display itself. This facilitated passage of ASCII characters from microprocessor registers to the display buffer through a single memory location. Ten display initialization flags (listed in hexidecimal notation)

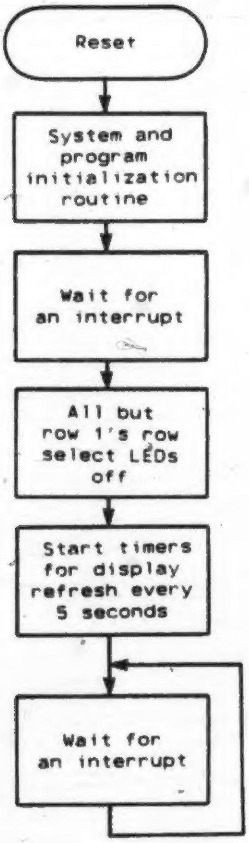
Reset
System and program initialization routine
Wait for an interrupt
All but row 1's row select LEDs off
Start timers for display refresh every 5 seconds
Wait for an interrupt

Figure 4.5 Potato planter monitor program flow chart

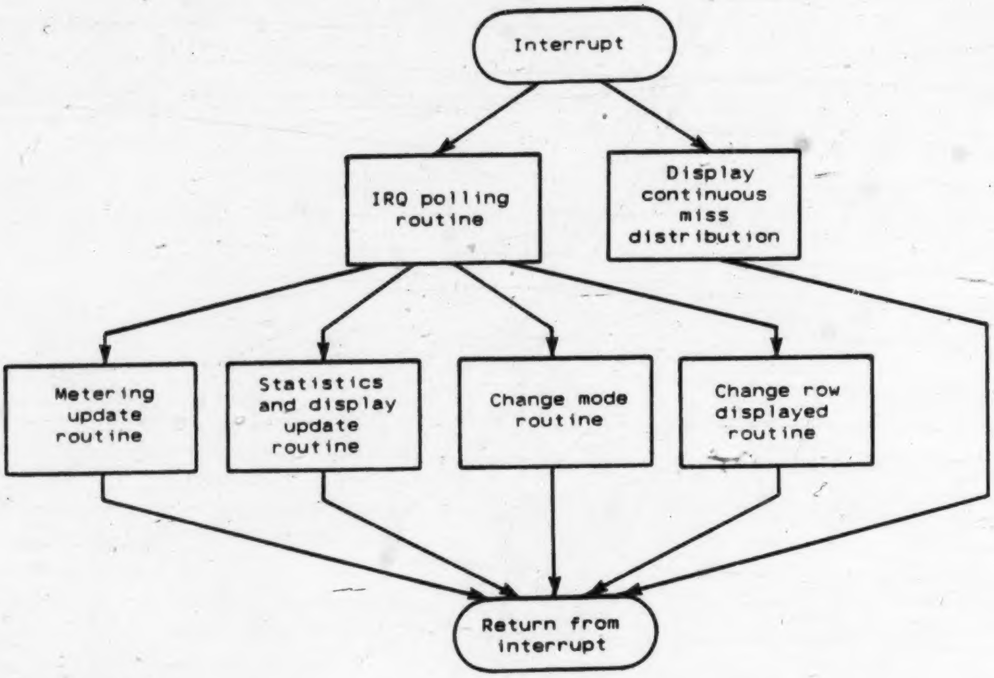
Interrupt
IRQ polling routine
Display continuous miss distribution
Metering update routine
Statistics and display update routine
Change mode routine
Change row displayed routine
Return from interrupt

Figure 4.6 IRQ service routine flow chart

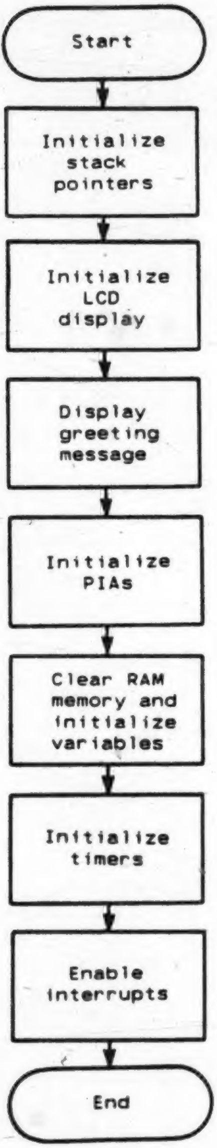
Start
Initialize stack pointers
Initialize LCD display
Display greeting message
Initialize PIAs
Clear RAM memory and initialize variables
Initialize timers
Enable interrupts
End

Figure 4.7 Initialization routine flow chart

were sent to the display in the following order.

1. 68 reset blank display
2. 6B set visible cursor
3. 61 set blinking cursor
4. 6D set cursor line
5. 62 reset blinking display
6. 65 auto increment cursor
7. 67 set up for increment
8. 6E reset rapid load
9. 00 blank characters
10. 8A clear display

The subroutine short delay, SDELAY, was used to give the display ample time to set up. After the flags were sent to the display, the display was cleared by the subroutine CLRLCD.

To display a message, a series of ASCII characters were fed to the LCD display with a short delay after each character to allow for latch time. The greeting message, "$POTATO MONITOR$", was displayed on the LCD immediately after a reset condition.

A PIA reset was necessary to initialize the PIAs in their direction of data transfer and to set initial operation conditions. Row PIAs were initialized with port A as inputs and port B as outputs with the CA1 control line enabled. Therefore, a transition on line CA1 would cause an interrupt in the system when a metering event ocurred. Side B was initially set to FF in order to shut all the metering LEDs off. The microswitch PIA was initialized with both sides as inputs, port A corresponding to the number of rows, and port B the number of metering elements per row.

A memory initialization routine cleared all RAM locations prior to planter operation. The RAM locations, starting with D000 and ending with D7FF were sequentially set to 00. Program variables then were initialized.

Microswitch settings were read and their values were stored accordingly. An initial memory offset for the number of consecutive misses per element was calculated by adding 10 to the number of elements per row.

The primary task of the PTM reset was to initialize the timers to produce an interrupt every five seconds for purposes of the statistics update and display refresh. Timer latches 2 and 3 were loaded with decimal values 44642 and 50 respectively. Timer 2 was set for 16-bit operation, continuous mode, output enabled, interrupt mask set and internal clock. Timer 3 was set for external clock, 16-bit operation, continuous mode with both the interrupt and output enabled. All timers were preset until a metering event occurred.

4.3.2.2 Main Program

The main program was engaged on the first metering event after start up. PTM timers were started and the display mask 11011111 (binary notation) was sent to port B on PIA1 to illuminate row one's row-select LED.

The primary purpose of the main program was to have instructions for the processor to execute if none of the interrupt service routines were engaged. As such the interrupt-driven main program contained a CWAI instruction which enabled interrupts and stacked all registers in anticipation of the next interrupt. Once an interrupt occurred and was serviced, program control returned to the main program.

4.3.2.3 IRQ Service Routines

The IRQ interrupt service routines performed a number of functions including: user-generated row and mode change requests, metering performance updates, statistics update, and sensor malfunction tests. Upon entering the IRQ service routine, interrupts are disabled by setting bits 6 and 4 of the condition code register. Figure 4.8 provides a flow chart of the IRQ polling routine. Each device connected to the IRQ line was polled in sequence to identify the source of the interrupt. Bit 7 (B7) of the interrupting PIA's status register was set. Upon identifying the source of the interrupt, the program flow was directed to the appropriate service routine. Row PIAs were checked

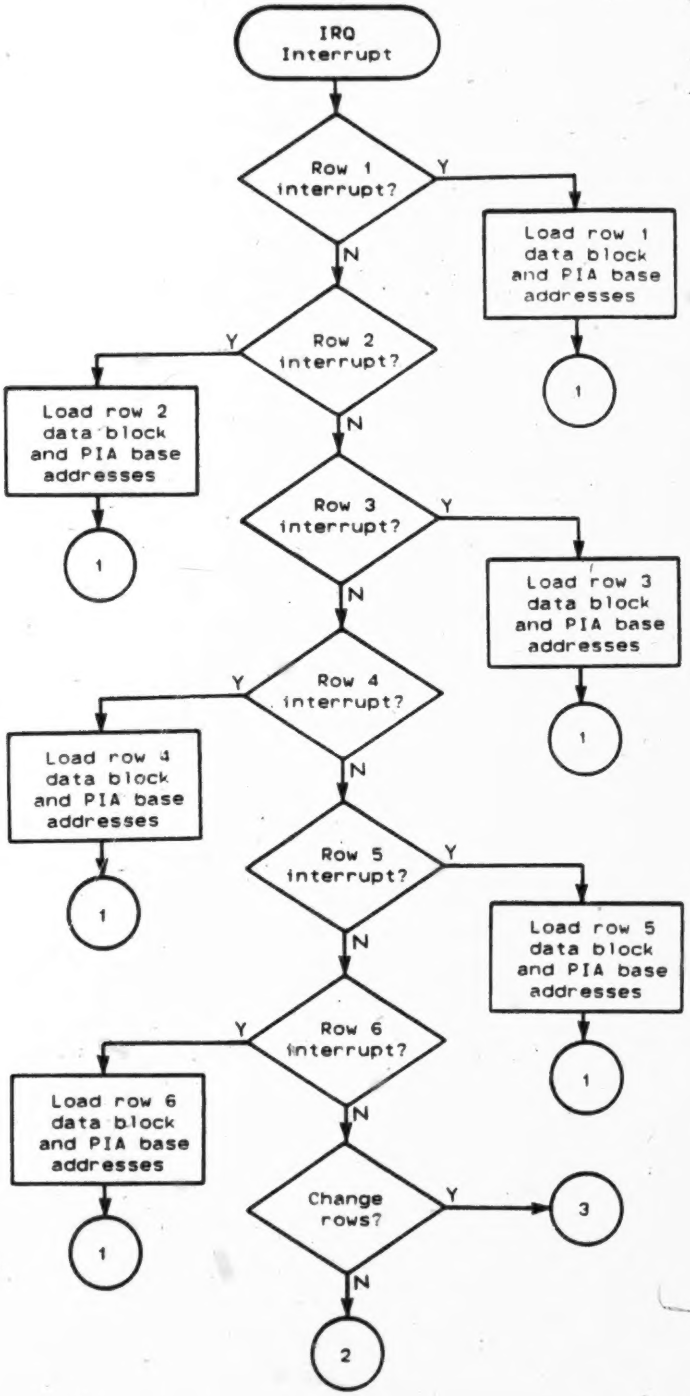
IRQ Interrupt
Row 1 interrupt?
Y
N
Load row 1 data block and PIA base addresses
1
Row 2 interrupt?
Y
N
Load row 2 data block and PIA base addresses
1
Row 3 interrupt?
Y
N
Load row 3 data block and PIA base addresses
1
Row 4 interrupt?
Y
N
Load row 4 data block and PIA base addresses
1
Row 5 interrupt?
Y
N
Load row 5 data block and PIA base addresses
1
Row 6 interrupt?
Y
N
Load row 6 data block and PIA base addresses
1
Change rows?
Y
3
N
2

Figure 4.8 IRQ polling routine flow chart

first to determine if a metering event had occurred. If a metering event was not indicated, the microswitch PIA was polled to see if a row change had been requested. Barring successful identification of an interrupting device, the program defaulted to the statistics update and display refresh routines. A return from interrupt (RTI) instruction was placed at the end of every service routine to direct program flow back to the main program.

When a metering event was detected, the base address of the data block containing the row's metering statistics was loaded into the X register and the base address of the interrupting PIA is loaded into the Y register. This allows relative addressing to be used in the metering update routine.

4.3.2.4 Metering Update

Metering update logic is illustrated in Figure 4.9. When a metering event is indicated a check is made to determine whether a previous metering event has ocurred since the last statistics update. If not, a potato sensor malfunction test is performed. In this manner all potato sensors are checked for proper function once every five seconds. Further comment on defective sensor checks can be found in section 4.3.2.10.

Program variables affected by the metering update routine are defined on lines 78 to 89 of the program

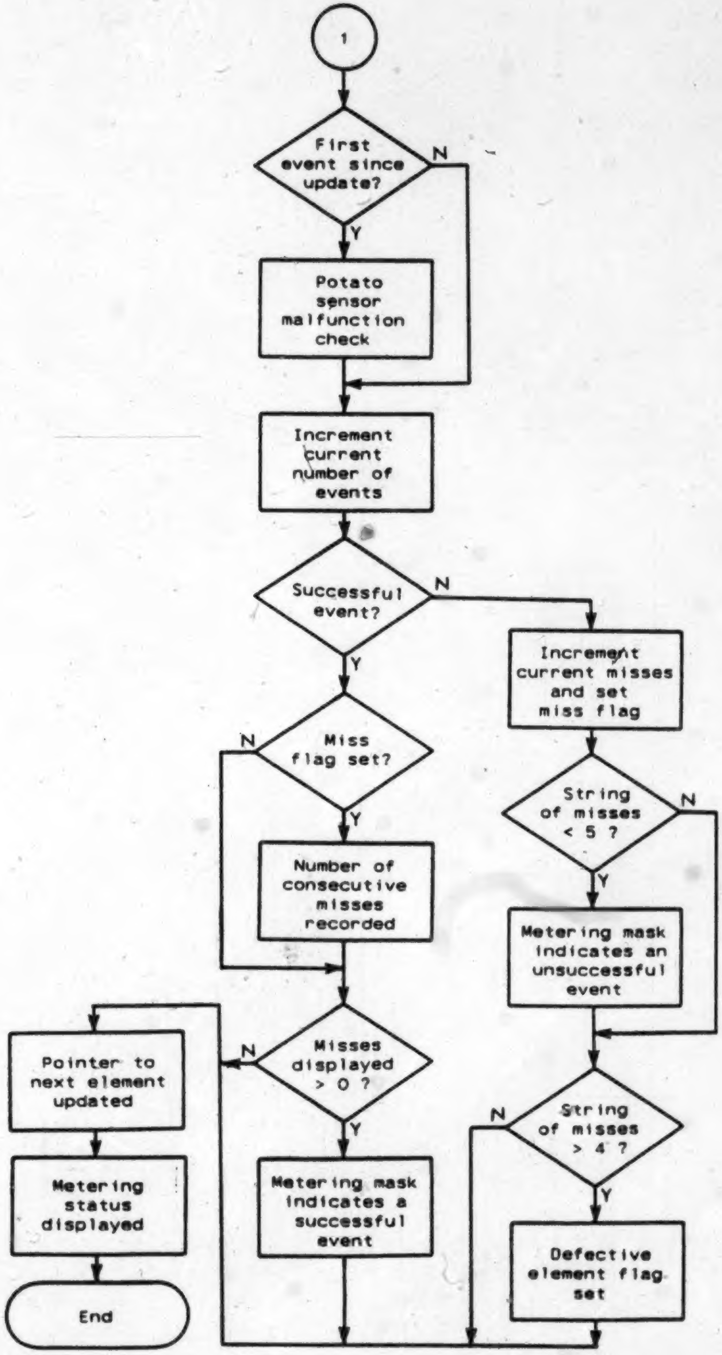
1
First event since update?
N
Y
Potato sensor malfunction check
Increment current number of events
Successful event?
N
Y
Increment current misses and set miss flag
Miss flag set?
N
Y
Number of consecutive misses recorded
String of misses < 5 ?
N
Y
Metering mask indicates an unsuccessful event
Misses displayed > 0 ?
N
Y
Pointer to next element updated
String of misses > 4 ?
N
Y
Metering status displayed
Metering mask indicates a successful event
Defective element flag set
End

Figure 4.9 Metering update flow chart

listing (Appendix E). The memory offsets from data block base addresses also are listed. A metering update addresses only the data block associated with the interrupting PIA. The current events counter (CNEV) is incremented before a check for a successful metering event is performed (bit 7 of port A = 1). If a metering error has occurred the current metering error counter (CNMISS) is incremented and a check is done on the number of consecutive misses (MISLED). If less than four of the yellow metering LEDs are illuminated, the top unlit metering LED is turned on and the number of misses displayed (MISLED) is incremented. A lookup table was used to determine the LED mask which represents the number of consecutive metering errors.

If a particular metering element consistently failed, a buzzer was sounded. This necessitated keeping track of how each element in the metering chain performs. Variable NEXTEL contains the offset from the data block's base address to the memory location containing the count of consecutive misses associated with the interrupting metering element. Should the successive metering errors be greater than four, the buzzer is turned on, otherwise the the number of consecutive misses for that element is incremented.

If bit 7 on port A of the interrupting PIA is zero a successful metering event is indicated. The number of consecutive misses displayed on the yellow metering

LEDs are checked and if greater than zero, the top-most illuminated LED is turned off.

A successful metering event indicates that the interrupting metering element is functioning properly and, therefore, the consecutive miss count for that element is zeroed. The offset to the memory location of the next element to be monitored in the interrupting row is then decremented. If a complete cycle of the metering chain is indicated, the offset (NEXTEL) is reset to point to the memory location corresponding to the next expected metering element.

The monitoring system could only display metering performance statistics on the LCD display one row at a time. This required the row select mask (LEDROW) to be and-ed with register A to preserve the row select indicator (green status LED). At this point the status word in register A contains current metering and system status information for the interrupting row. Metering and status LEDs then were updated by sending the contents of register A to the interrupting PIA's B data port.

4.3.2.5 Statistics Update

Upon an interrupt from clock 3 of the PTM (every 5 s), the statistical update took place as illustrated in Figure 4.10. Data blocks for each row were updated in an iterative manner by the statistics calculation subroutine CALC (Figure 4.11). Five statistics are

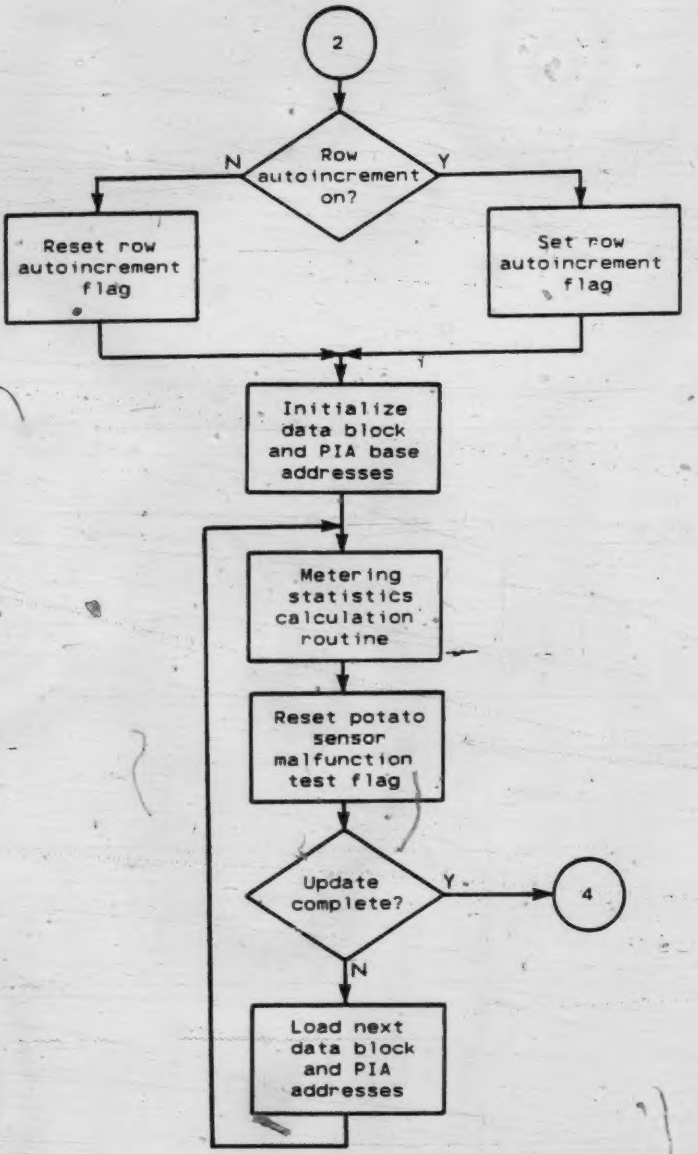
2
Row autoincrement on?
N
Y
Reset row autoincrement flag
Set row autoincrement flag
Initialize data block and PIA base addresses
Metering statistics calculation routine
Reset potato sensor malfunction test flag
Update complete?
Y
4
N
Load next data block and PIA addresses

Figure 4.10 Statistics update flow chart

derived in the calculation routine: planting rate, current percent misses, total number of events, total number of unsuccessful metering events, and total number of successful metering events. The statistics update routine performs the additional function of checking for a malfunctioning metering event sensor. After performance statistics have been updated and sensor checks performed, the LCD display is refreshed with updated values and PTM timer 3 is reloaded to count down the time to the next update.

Planting rate is expressed in plants/min and is calculated by multiplying the current number of events by 12, the number of updates in a minute. The 2 byte result is stored in PLRATE.

The current percentage of metering errors is calculated by dividing the product of the current number of events (CNEV) and 100 by the current number of misses (CNMISS).

The total number of events (TEVENT) was updated by adding the current number of events (CNEV) to the total number of events. The address of TEVENT was loaded into the X register and CNEV was loaded into the A register in preparation for the addition subroutine call. If the planter was operating and no metering events occurred in the last five seconds, variable CNEV would be zero and, thus, a malfunctioning metering sensor was assumed. Metering sensor malfunction was indicated by

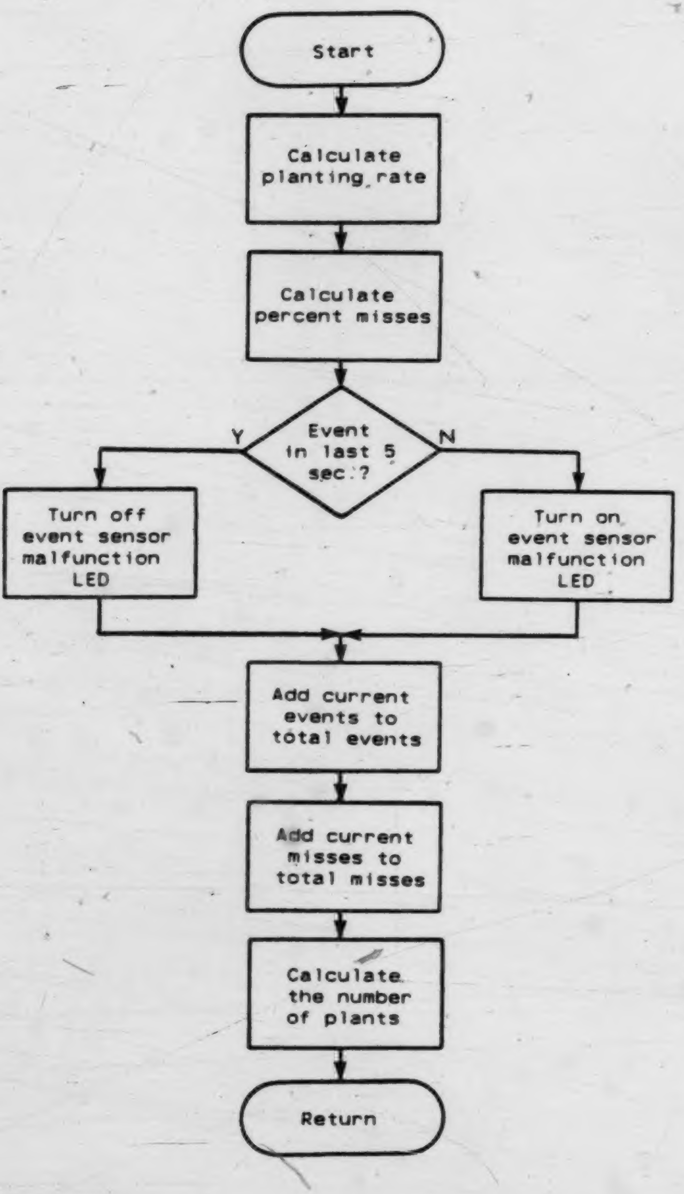
Start
Calculate planting rate
Calculate percent misses
Event in last 5 sec.?
Y
N
Turn off event sensor malfunction LED
Turn on event sensor malfunction LED
Add current events to total events
Add current misses to total misses
Calculate the number of plants
Return

Figure 4.11 Statistics calculation flow chart

illuminating the bottom red status LED while successful malfunction tests ensure malfunction indicators were turned off. Section 4.3.2.10 contains further sensor malfunction discussion. After returning from the addition routine, the current number of misses is zeroed in preparation for the next calculation routine call.

The addition of current number of misses (CNMIS) to the total number of misses (TMIS) proceeds in a similar fashion with current number of misses being zeroed after returning from the addition routine.

A running total of the number of potatoes planted is calculated by subtracting the total number of misses from the total number of events.

4.3.2.6 Mode Change

The NMI service routine was entered only after the push button switch for a mode change caused the NMI* pin of the processor to go low. This indicated a user request to change the performance statistic on the monitor's LCD display. Routine logic is presented in the mode change flow chart in Figure 4.12. The mode counter was updated before the statistic for the next mode was displayed. Thus a wrap-around to the first mode occurred when successive mode change requests exceeded the number of modes. Mode number assignments and labels were: 0 - "% MISSES", 1 - "NO. EVENTS", 2 - "NO. MISSES", 3 - "NO. PLANTS", 4 "POTATO/MIN". Once

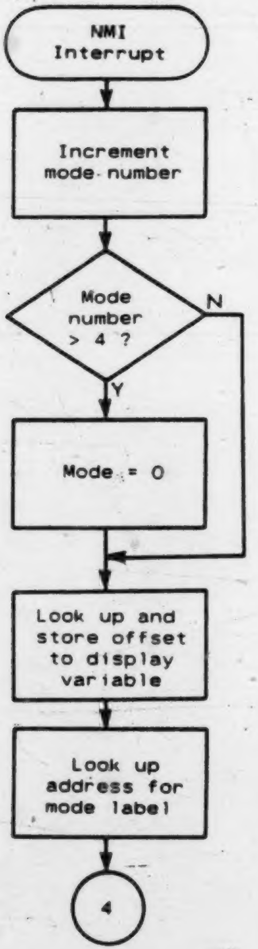
NMI Interrupt
Increment mode number
Mode number > 4 ?
N
Y
Mode = 0
Look up and store offset to display variable
Look up address for mode label
4

Figure 4.12 Mode change flow chart

the new mode was selected, the processor would execute the subroutine DISPLY to display the correct performance information on the LCD.

4.3.2.7 Row Change

The row change routine updates program variables and system status upon a user request to display the selected performance statistic from another row. A wrap-around strategy similar to the one discussed in section 4.3.2.6 was used. The flow chart in Figure 4.13 sets out routine tasks. The current row's row-select LED is turned off and the row-select LED of the new row is illuminated. PIA and data block base addresses are updated before returning from the subroutine call.

4.3.2.8 Display Refresh

The purpose of routine DISPLY was to display the correct descriptor, for example, "POTATO/MIN", and the corresponding performance statistic (Figure 4.14). This required the proper string of ASCII characters to be assembled in successive memory locations before being dumped to the LCD. ASCII codes for mode descriptors were arranged in the first ten memory locations after the variable DUMP. The subroutines HEXVAL and CONVAL were then called to obtain the correct ASCII codes representing the value of the performance statistic. The next six DUMP memory locations were filled with the resulting ASCII characters. After the LCD was cleared

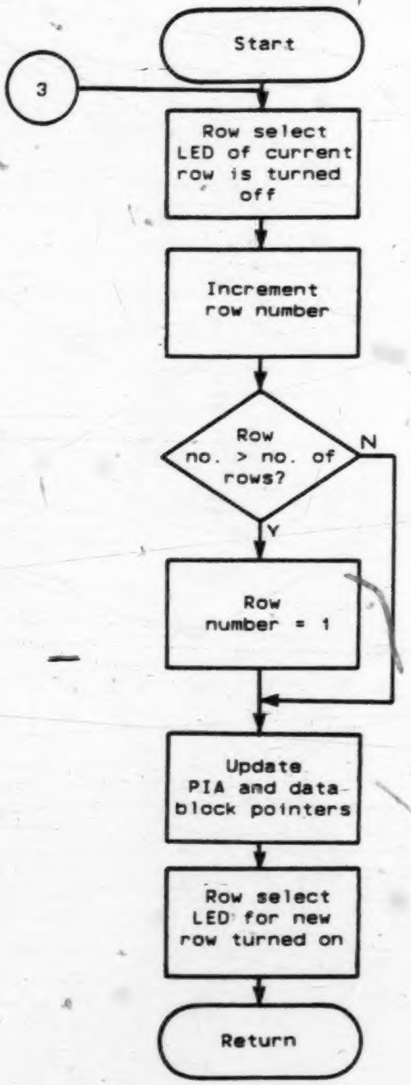
Start
3
Row select LED of current row is turned off
Increment row number
Row no. > no. of rows?
N
Y
Row number = 1
Update PIA and data block pointers
Row select LED for new row turned on
Return

Figure 4.13 Row change flow chart

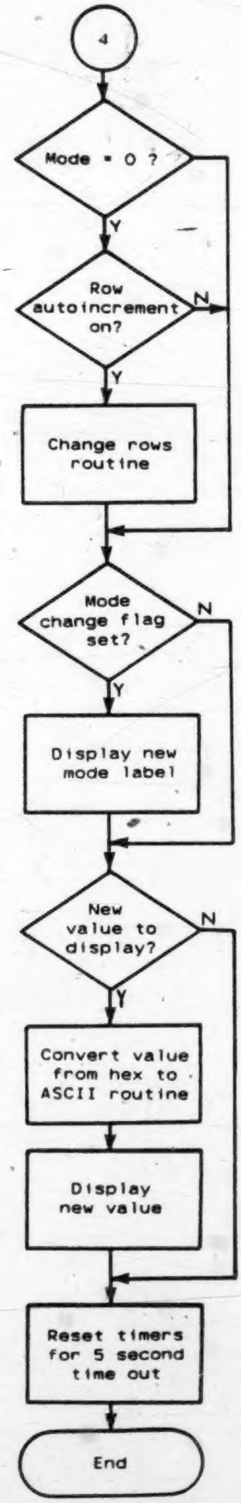
4
Mode = 0 ?
Y
Row autoincrement on?
N
Y
Change rows routine
Mode change flag set?
N
Y
Display new mode label
New value to display?
N
Y
Convert value from hex to ASCII routine
Display new value
Reset timers for 5 second time out
End

Figure 4.14 Display refresh flow chart

by the CLRLCD routine, the ASCII characters were sent to the display at 0.78 ms intervals.

The purpose of the CLRLCD subroutine was to send flags 8A and 00 to the LCD in order to clear the display and enable the transfer of ASCII characters for display. A short delay was used to ensure character codes were transfered properly.

The short delay subroutine (SDELAY) simply decremented a counter causing a 0.78 ms delay before returning to the calling program.

4.3.2.9 Code Conversion

HEXVAL was the subroutine that chose the correct performance statistic indicated by the MODE counter. Program flow details are shown in Figure 4.15. The value chosen was stored in a two byte variable called VALHEX.

The subroutine CONVAL converted the hexadecimal representation of the performance statistic to be displayed into an ASCII character string. The selected two byte hexadecimal performance statistic was translated to five decimal counters by means of successive comparisons of the value in VALHEX to multiples of the base ten. The counter values then were converted to ASCII character codes and leading zeros were replaced with blanks by routine LDZERO. ASCII character codes then were appended to the last occupied memory location of variable DUMP. The decimal counters

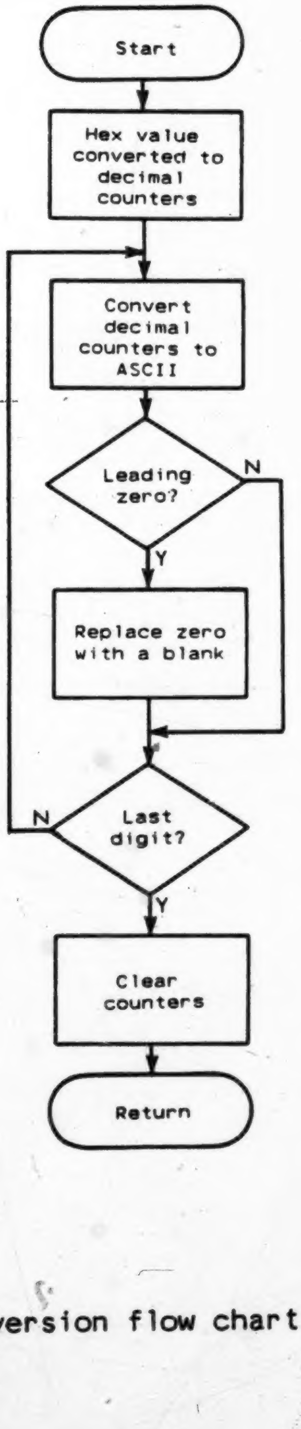
Start
Hex value converted to decimal counters
Convert decimal counters to ASCII
Leading zero?
N
Y
Replace zero with a blank
Last digit?
N
Y
Clear counters
Return

Figure 4.15 Code conversion flow chart

then were cleared for the next conversion.

4.3.2.10 Malfunctioning Sensor Check

Both the potato sensor (photoscanner) and the metering event sensor (Hall Effect switch) have malfunction checks associated with them. A metering event sensor malfunction is assumed if a metering event has not taken place since the last statistics update. Although this mode of operation will indicate a problem when the planter stops operating, the operator obviously will be able to discriminate between a halt and a problem signal.

In order to detect a malfunctioning potato sensor, a check was made to see if the desiginated photoscanner had an output signal of +5 V (beam intact). The desiginated photoscanner refers to a photoscanner from a non-interrupting row that theoretically is unobstructed. Base addresses for the PIAs and the data blocks corresponding to the desiginated photoscanners were assigned, in the inilization routine (section 4.3.2.1), to each data block in variables beginning with LKDAT and LKPIA, respectively. Subroutine FAIL performs the sensor malfunction test by checking for a '0' (fail) in bit 7 (photoscanner output) of port A of the designated PIA. If a potato sensor malfunction is detected the top status LED (red) is turned on, otherwise the LED is turned off. Refer to section 4.3.2.4 for the potato sensor malfunction algorithm.

4.4 Potato Planter Simulator

The two-row potato planter simulation unit shown in Figure 4.16 was constructed for program debugging, system performance assessment, and demonstration purposes. Two horizontal axles were aligned vertically and their pillow block bearing mounts were fastened to an angle iron frame. On each axle were two sprockets, one for each row. An endless chain with six equally spaced metal cups was installed between the vertically aligned upper and lower sprockets. Sensors were mounted on an adjustable arm that extended past the path of the metering chain. Ceramic permanent magnets, 13 mm in diameter and 7 mm thick, were bonded to the lower edge of each cup with south poles facing outward. Sensors were positioned such that metering status could be determined in the manner discussed in section 3.3.3. Figure 4.17 presents the position of monitor sensors. Styrofoam cups were used in place of real potatoes and could be arranged to simulate a pattern of misses. The 0.18 kW, variable-speed electric motor provided power to the simulation unit.

4.5 Performance Analysis

A detailed performance assessment of the potato planter monitoring system was not undertaken, however, general observations were noted and areas for improvement are discussed.

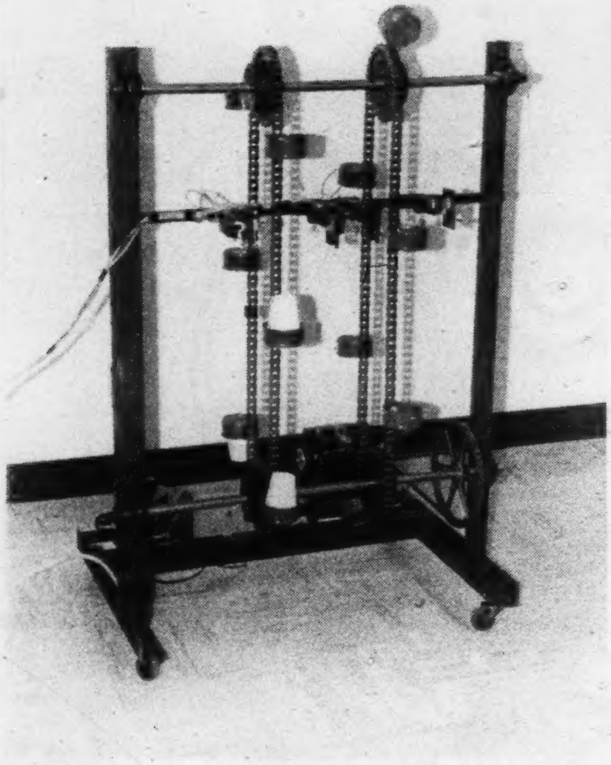

Figure 4.16 Potato planter simulation unit

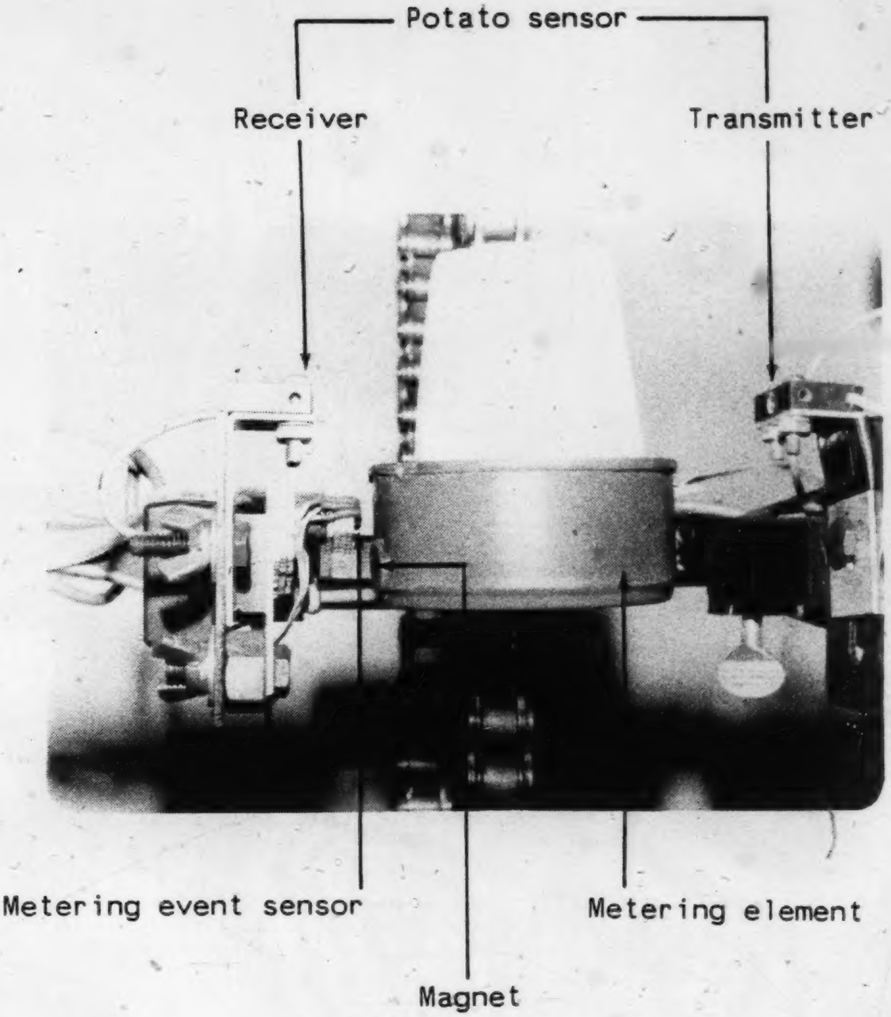
Potato sensor
Receiver
Transmitter
Metering event sensor
Metering element
Magnet

Figure 4.17 Sensor arrangement on the planter simulator

4.5.1 Microprocessor Board and Software

The basic microprocessor system and software performed to a satisfactory level. Simulated planting rates of 700 plants/min produced very predictable feedback. Metering rates past 800 plants/min began to reflect system loading conditions, and resulted in a small proportion of misses going undetected. The cause of system instability above 800 plants/min was attributed to both chain slap on the simulator unit and actual system loading conditions. However, causes of metering rate limitations were not determined directly. Accurate monitoring of planter performance under simulated conditions can be maintained up to equivalent ground speeds of 9 km/h for two rows, 6 km/h for four rows, and 3 km/h for six rows assuming a 30 cm plant spacing. Improvements to input/output algorithms are discussed in section 4.6 and, if implemented, would improve the monitoring system's operating efficiency.

All performance statistics calculations were carried out as expected. The metering rate calculation takes a five second display cycle to stabilize after each row change request. Metering rate accuracy could be improved if the metering events from each row were summed every five seconds. The resulting metering rate would represent the planter's metering rate rather than the metering rate for a single row.

Input and output functions and associated hardware performed well over an estimated one hundred thousand test and demonstration metering events. Mode-change and row-select functions operated smoothly and the autoincrement and buzzer switches functioned properly.

4.5.2 Input Device Evaluation

All system input devices performed their designated function. The metering event sensor on row 1 of the simulation unit was configured with a ceramic magnet backing as discussed in section 3.3.2 whereas the row 2 metering event sensor had a 13 mm diameter by 25 mm long aluminum nickel alloy magnet backing. Row 1 tolerated a sensor-to-magnet spacing of roughly 5 mm while row 2 had double the spacing tolerance.

The potato sensor performed exceptionally well and operated to its rated 50 cm range. Under actual field conditions, lens obstruction from dust or seed chips is possible. A "chalk brush" test covered the lens with a substantial layer of chalk dust yet the sensor unit still performed to design expectations.

Metering and potato sensor configuration in relation to one another is an important aspect to ~~the~~ overall design perspective. The sensor mounts on the potato planter simulator could be adjusted in the x, y and z planes. Magnet attachment to metering elements posed another challenge worthy of mention. Considering the repeated impacts of potato seed in the seed reservoir and possible bond fracture due to the harsh Canadian winters, bolting magnets to the metering elements seems more advantageous than a bonding solution.

Microswitches met the need for a means to set planter configurations. Although a more sophisticated input device would look nicer, placement of microswitches inside the monitor unit is worthy of consideration since parameter settings are rarely altered.

4.5.3 Output Device Evaluation

The output devices discussed under sections 4.2.1.3 performed well and gave a clear, straightforward representation of the planter simulator operation. The metering and status LEDs could be located in the operator's peripheral vision and, by pure color discrimination, the performance of the planter would be known without looking directly at the monitor. The information on the LCD display would be secondary during field operations but would provide useful information at a glance. The mode-select function would enable the operator to choose among performance statistics according to the type of information desired. Having a row autoincrement option allowed the percentage of misses to be displayed for each row in an alternating fashion. This function was thought to be of value since it presents performance information for the total planting system without diverting the operator's attention.

Both metering event sensor and potato sensor malfunctions were detected without fail. Indicators for metering sensor malfunction served a dual purpose since the signal producing magnets on metering elements were a component of the last moving part in the drive chain. Thus, all drive train malfunctions will be indicated through the metering event sensor malfunction LED.

The one drawback of the LCD display was that of the long (0.78 ms) set-up time needed for each character. A slight refinement to system software could prevent the unnecessary repetition of identical display segments. The current delay caused by character transfer contributed to system loading at high metering rates.

The current monitor unit was suited for a two-to six-row row planter. A dash mount would require a top-view LCD whereas a ceiling mount obviously would be suited to a bottom-view LCD screen.

The buzzer, unquestionably, would alert operators to the problem of a defective element in the metering chain. At times the buzzer was annoying but could be silenced with the buzzer disable toggle switch. The case of two potatoes becoming lodged in a cup or the occurrence of bent picks are aspects which the defective element test is designed to detect.

4.6 Design Discussions

Although the potato planter monitoring system met the first five design criteria listed in section 4.1.2, the sixth design criteria, efficient operation under field conditions, was not directly met since the monitoring system was not field tested. Improvements to the existing monitoring system would enable the potato planter monitor to be used as a means for assessing potato planter performance on existing cup and pick-type planters. The following discussion outlines the author's suggestions for system improvements.

Perhaps the biggest drawback to the system is the limited capacity for field data acquisition. A row spacing of 90 cm and a plant spacing of 30 cm gives each potato plant a growing area of 0.27 m^2. Therefore, a quarter-section of potatoes requires nearly 2.4 million seed pieces. In order to tabulate the metering status for all metering events, program variables having totals greater than can be represented by two bytes (65,536) should be expanded to three bytes. Computational routines need to be adapted accordingly. A monitoring system based on a three byte system will accommodate up to 16.8 million metering events, or data for approximately 450 ha whereas the present two byte system will handle only 1.75 ha of metering data.

Improvement of the display refresh routine to avoid the costly 13 ms delay every 5 s would improve the system's operating efficiency. Although this delay does not appear to be overly significant, the system performance can be affected. This applies especially to the defective element tests, which rely on the consistent logging of metering status.

The suggestion is made that additional modes be implemented, such as ground speed and time rate of area covered. This would greatly enhance the monitor's capabilities.

A number of hardware improvements are needed if the monitoring system is to proceed to the production phase. The design and development of printed circuit boards would enhance system flexibility, ease hardware assembly requirements, and allow for component interchange. The following circuit modules are suggested: a board for the basic microprocessor system, add-on input/output boards for each row, a display board, and a sensor junction module board. A keypad for operator input would be more aesthetically pleasing than the push buttons currently used and would have the added benifit of providing the input hardware for additional user options.

A five-volt switching regulator is suggested for the monitor's power circuit.

Installation of a non-volatile RAM with a battery back-up power circuit would enable the metering performance data to be retained if the monitor was removed from the tractor. This is an important addition since growers may choose to download their performance data to a micro-computer for further analysis.

The most important factor for successful implementation of the monitoring system is the accuracy of sensor placement. Development of a sensor mounting system which allows stable sensor positioning relative to one another in the x, y, and z planes is necessary if the dual-sensor, event-triggered system is to be effective. Sensor system mounts must provide a flexible means of attachment to the planter's frame. Reliable data acquisition also depends on the stability of the metering mechanism. Pick-type planters do not present this problem, however, an idler may be required near the sensor system mounts on cup-type planters if chain or belt vibration is to be avoided.

5. SUMMARY AND CONCLUSIONS

The need for a means of assessing potato planter performance is based on the quantitative and qualitative improvements to potato yields that can be achieved with a uniform planting pattern. The seed - metering mechanism interaction is specific to the type of metering mechanism, seed piece attributes, and the operating conditions during planting. Control over seed piece attributes, such as size and shape, depends on the size distribution of whole seed tubers and the manner in which they are cut.

Seed attributes affect main stem density and the uniformity of planting patterns in an independent manner. The shape and size of seed pieces play a key role in determining the uniformity of planting pattern, the number of stems per seed piece and the number of stems per unit area. Therefore, seed attributes strongly influence the yield and size distribution of harvested tubers.

The critical nature of the planting process calls for potato planter performance experiments to produce meaningful results. Separating the metering and placement aspects of planter performance will help researchers and growers to understand better how planting parameters influence yields. Planter performance experiments should contain a full description of seed material used and, with studies on placement performance, the standard deviation of seed placement should be reported. The CV statistic is a useful measure of placement performance as long as the mean seed spacing is close to the intended seed spacing. Comparisons made otherwise are misleading from a performance perspective.

If planter performance studies reported the distribution of consecutive metering errors, the effect of planting pattern on yield could be assessed by taking into account the variable yield compensation effect exerted by plants adjacent to a number of missing plants.

After careful consideration of the experimental procedure and the statistical analysis, the following conclusions were drawn.

1. Assessment of potato planter metering and placement performance can be carried out in an independent manner.

2. Compatibility between pick-type metering mechanisms and seed material improves as metering rate increases from 3 plants/s to 9 plants/s and as the number of cut surfaces on the seed pieces increases from one to three. Therefore a pick-type planter's metering performance responds favorably to high metering rates and blocky seed pieces.

3. Seed pieces weighing 45 g produce fewer metering errors than 60 g seed pieces at metering rates up to 6 plants/s in pick-type planters.

4. Seed piece shape and size affect the occurrence of metering errors in an independent manner, however, a strong interaction exists between seed shape and metering rate, and seed piece size and metering rate.

5. Cut 45 g and 60 g seed pieces have a more consistent metering performance compared to 50-100 g whole seed tubers when using a pick-type planter, especially at metering rates below 6 plants/s.

The following conclusions are put forth for the design and development of the potato planter monitoring system.

1. The dual-sensor event-triggered system provides an effective means of detecting metering errors for cup and pick-type potato planters.

2. Sensor positioning is critical for accurate determination of metering errors. Secure sensor mounts and the ability to adjust sensors in all three planes are critical aspects of monitoring planter performance in a reliable manner.

3. The potato planter monitoring system is capable of providing valuable performance feed back to operators. Indicator mechanisms that relay the number of consecutive misses for each row, drive train malfunction, sensor malfunction and performance statistics such as metering rate and percent of metering errors, all contribute toward the efficiency of the planting operation by improving the quality of information available to the operator.

4. Data logging capabilities of the potato planter monitoring system can establish the pattern of consecutive metering errors and thereby provide growers with the performance information needed to accurately assess the actual population density effects on yield.

6. RECOMMENDATIONS FOR FURTHER STUDY

Separate field experiments for potato planter metering and placement performance is encouraged. A four-row or six-row planter with a monitoring system would serve as an excellent experimental unit for field metering performance experiments. A suggested method of conducting potato placement experiments is through a series of high-speed 16 mm film clips. Digitial characterization of the placement sequence would assist in determining the effect of placement parameters.

Further experimentation on the effect of seed piece shape and size will help define how seed pieces and metering mechanisms interact in terms of metering performance. Experimental procedures could be improved if a photoscanner was positioned below the point of seed release. This would allow the number of seed pieces to be counted as they fell and would enable researchers to determine the actual seed rate and the number of doubles.

Planter performance investigations and yield response studies using small whole tubers (40-70 g) would provide valuable information for assessing the costs, benifits and alterations to planting operations and potato machinery that are required for potato production with small whole seed tubers.

Expressing metering performance as a function of seed piece surface area ratios may prove to be advantageous. A skin surface area to total surface area ratio, or a skin surface area to cut surface area ratio, can be used to define both seed shape and seed size effects on a metering performance continuum. Another facet of seed attributes that may be worthy of investigation is the relationship between surface area ratios and the total and marketable yields. Establishing seed piece yields and planter performance in terms of seed attributes would serve as a good starting point for a potato planting model. By implementing planting parameters of greatest utility to the grower, under-utilization of agricultural inputs can be avoided and yields will be enhanced accordingly.

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8. APPENDIX A. METERING DATA ANALYSIS PROGRAM

```
10   'Program name:  HITMISS.BAS
20   'Purpose:       To analyse potato planter metering data
50   'Programmed for:IBM PC
60   'Language:      BASICA
70   'Programmer:    Edward J. Hauck
80   '-------------------------------------------------------------------------
90    '
100   ' ** MAIN PROGRAM **
102   '
104   GOSUB 200                 '   Program initialization
105   '                        * CUT SEED METERING DATA *
106   FOR M=1 TO 3              '   Metering rates 1-3 (3, 6 and 9 plants/s)
108      FOR H=1 TO 3           '   Seed shapes 1-3 (1-cut, 2-cut and 3-cut)
110         FOR Z=1 TO 2        '   Seed size 1-2 (45 g and 60 g)
112            FOR R=1 TO 5     '   Replications 1-5
113               FILE$ = "M"+RIGHT$(STR$(M),1)+"H"+RIGHT$(STR$(H),1)+"Z"+_
                          RIGHT$(STR$(Z),1)+".R"+RIGHT$(STR$(R),1)
114               GOSUB 300     '   Data file analysis (% metering errors and
115                             '     and distribution of consecutive misses)
117            NEXT R
122        NEXT Z
128      NEXT H
134   NEXT M
136  '
137  '                         * WHOLE SEED METERING DATA *
138   FOR M=1 TO 3              '   Metering rates 1-3 (3, 6 and 9 plants/s)
140      FOR R=1 TO 5           '   Replications 1-5
14          FILE$ = "M"+RIGHT$(STR$(M),1)+"HO"+".R"+RIGHT$(STR$(R),1)
142         GOSUB 300           '   Data file analysis (% metering errors and
143                             '     distribution of consecutive misses)
145      NEXT R
150   NEXT M
152   GOSUB 800                 '   Output for percent metering errors
154   GOSUB 900                 '   Output for consecutive metering errors
156   LOCATE 12,25:PRINT "FINISHED  ";:PRINT CHR$(7)
158   END
160   '-------------------------------------------------------------------------
162   '
200   ' ** Program initialization **
205   '
210   CLS
215   DIM OP$(110,5),CMISS(110,70)
220   M = 1:H = 1:Z = 1:R = 1:NO = 1
225   FILE$ = "":L.FILE$ = ""
230   TPU1$ = " File         Misses Hits Events %Misses"
235   PU1$  = "\          \   ##    ##   ###    ###.#"
240   PU2$  = "\          \"
245   TPU3A$ = "  Frequency distribution of consecutive metering errors"
250   TPU3B$ = "               1   2   3   4   5   6   7   8   9  10"
255   TPU3C$ = "              11  12  13  14  15  16  17  18  19  20"
260   PU3$   = "              ##  ##  ##  ##  ##  ##  ##  ##  ##  ##"
265   RETURN
270   '-------------------------------------------------------------------------
275   '
300   ' ** Data file analysis (% metering errors and and distribution of
305   '    consecutive misses) **
310   '
335   LOCATE 12,30:PRINT "Crunching: ";FILE$;
340   LOCATE 14,20:PRINT "Last file: ";L.FILE$;"  ";"% MISSES: ";MISS
345   I% = 1:MISS = 0:HIT = 0
```

```
350  OPEN "I",#1,"B:"+FILE$
355  INPUT#1,EVENT$:INPUT#1,EVENT$:INPUT#1,EVENT$
360  INPUT#1,EVENT$
365  IF EOF(1) THEN GOTO 410
370  IF VAL(EVENT$) = 1 THEN HIT = HIT + 1:GOSUB 1000 ELSE IF VAL(EVENT$) = 0_
        THEN MISS = MISS + 1:CONFLG = 1:CON.MISS = CON.MISS+1 ELSE GOTO 360
375  IF I% = 100 THEN GOTO 390
380  I%=I%+1
385  GOTO 360
390  INPUT#1,EVENT$
395  IF EOF(1) THEN GOTO 415
400  IF EVENT$ = "1" OR EVENT$ = "0" THEN I%=I%+1
405  GOTO 390
410  GOSUB 1000
415  CLOSE 1
420  OP$(NO,1) = FILE$:OP$(NO,2) = STR$(HIT):OP$(NO,3) = STR$(MISS):_
       OP$(NO,4) = STR$(I%):OP$(NO,5) = STR$(MISS*100/I%)
425  NO = NO + 1
435  L.FILE$ = FILE$
440  RETURN
445  '----------------------------------------------------------------------
450  '
800  ' **  Output for percent metering errors
805  '
810  OPEN "O",#1,"RESULTS"
815  PRINT TUP1$
820  FOR  N=1 TO NO-1
825     LPRINT USING PU1$;OP$(N,1);VAL(OP$(N,2));VAL(OP$(N,3));VAL(OP$(N,4));_
          VAL(OP$(N,5))
830     PRINT USING PU1$;OP$(N,1):VAL(OP$(N,2));VAL(OP$(N,3));VAL(OP$(N,4));
          VAL(OP$(N,5));VAL(OP$(N,5))
835     PRINT#1,OP$(N,1);" ";OP$(N,2);" ";OP$(N,3);" ";OP$(N,4)
840  NEXT N
845  CLOSE 1
850  RETURN
855  '----------------------------------------------------------------------
860  '
900  ' ** Output for consecutive metering errors **
905  '
910  OPEN "O",#1,"MISTRING"
915  PRINT TPU3A$:PRINT TPU3B$:PRINT TPU3C$
920  FOR  N=1 TO NO-1
925    PRINT#1,OP$(N,1)
930    PRINT#1,USING PU3$;CMISS(N,1);CMISS(N,2);CMISS(N,3);CMISS(N,4);_
        CMISS(N,5);CMISS(N,6);CMISS(N,7);CMISS(N,8);CMISS(N,9);CMISS(N,10)
935    PRINT#1,USING PU3$;CMISS(N,11);CMISS(N,12);CMISS(N,13);CMISS(N,14);_
        CMISS(N,15);CMISS(N,16);CMISS(N,17);CMISS(N,18);CMISS(N,19);CMISS(N,20)
940  NEXT N
945  CLOSE 1
950  RETURN
955  '----------------------------------------------------------------------
960  '
1000 ' ** Check for string of consecutive misses **
1005 '
1010 IF CONFLG=1 THEN CMISS(NO,CON.MISS) = CMISS(NO,CON.MISS)+1
1015 CONFLG=0:CON.MISS=0
1020 RETURN
1025 '----------------------------------------------------------------------
```

9. APPENDIX B. METERING DATA

B1. Cut Seed Metering Data

The following data summary presents the cut seed metering trial results. Each data point represents one of five replications for each set of experimental variables.

Percent of metering events which were unsuccessful *

Seed piece attributes		Metering rate (plants/s)		
Shape	Size (g)	3.0	6.0	9.0
1-cut	45	50.2	50.8	47.1
		50.9	50.5	51.2
		18.2	8.4	46.4
		13.7	10.0	8.5
		10.7	15.4	5.0
	60	64.2	28.8	13.8
		70.2	36.0	13.4
		61.6	26.8	26.0
		60.2	34.3	13.3
		58.6	31.7	15.9
2-cut	45	32.9	17.9	16.8
		44.6	19.8	16.3
		41.6	22.1	8.1
		13.6	17.2	6.1
		15.7	34.9	20.1
	60	42.6	26.2	19.7
		29.7	27.4	13.0
		35.0	21.1	25.3
		44.5	23.5	19.3
		41.9	23.3	28.9
3-cut	45	18.4	9.9	10.5
		15.2	9.9	8.8
		44.8	18.2	13.1
		36.0	7.4	11.7
		15.1	11.8	6.5
	60	19.7	16.0	15.1
		25.3	6.0	16.3
		27.3	21.7	28.7
		47.2	22.3	11.6
		22.0	14.4	7.6

* Minimum of 100 metering events

B2. Whole Seed Metering Data

The data listed below summarizes whole seed metering results. Each data point represents one of the five experiment replications.

Percent of metering errors which were unsuccessful *		
Metering rate (plants/s)		
3.0	6.0	9.0
55.8	31.3	16.4
56.1	35.8	19.0
57.3	28.4	14.4
54.7	27.2	9.2
53.0	31.1	11.0

* Minimum of 100 metering events

B3. The following data set represents the distribution of consecutive metering errors expressed as a percent of total metering errors for cut seed metering trials.

	Percent of total metering errors									
	Consecutive metering errors									
Trial	1	2	3	4	5	6	7	8	9	10
M1H1Z1R1	13.5	16.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R2	22.5	6.8	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R3	12.8	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R4	9.2	3.1	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R5	7.6	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z2R1	4.8	10.9	14.3	5.4	0.0	0.0	9.5	0.0	6.1	6.8
M1H1Z2R2	6.1	5.6	6.7	17.8	2.8	13.3	7.8	4.4	0.0	0.0
M1H1Z2R3	11.2	14.2	12.2	6.1	5.1	6.1	3.6	0.0	0.0	0.0
M1H1Z2R4	8.4	10.5	6.3	12.6	7.9	3.2	0.0	0.0	4.7	0.0
M1H1Z2R5	13.6	12.1	12.6	3.7	9.3	2.8	0.0	0.0	0.0	4.7
M1H2Z1R1	20.9	5.8	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z1R2	15.8	9.9	8.9	9.9	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z1R3	10.7	6.6	12.4	3.3	4.1	0.0	0.0	0.0	0.0	0.0
M1H2Z1R4	8.7	3.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z1R5	13.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z2R1	22.2	6.2	4.6	6.2	0.0	0.0	3.6	0.0	0.0	0.0
M1H2Z2R2	20.3	6.1	1.3	1.7	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z2R3	14.1	7.5	4.2	3.8	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z2R4	11.5	9.2	5.5	11.1	0.0	5.5	0.0	0.0	0.0	0.0
M1H2Z2R5	18.5	8.6	10.3	3.4	0.0	2.6	0.0	0.0	0.0	0.0
M1H3Z1R1	12.3	2.7	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z1R2	15.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z1R3	12.5	11.0	0.0	6.0	2.5	3.0	3.5	0.0	0.0	0.0
M1H3Z1R4	12.1	10.1	3.0	4.0	0.0	0.0	7.1	0.0	0.0	0.0
M1H3Z1R5	12.7	1.7	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z2R1	10.3	5.9	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z2R2	7.4	14.9	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z2R3	10.3	6.9	3.4	0.0	0.0	0.0	8.0	0.0	0.0	0.0
M1H3Z2R4	12.1	12.9	2.4	6.5	8.1	0.0	5.6	0.0	0.0	0.0
M1H3Z2R5	11.1	8.5	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R1	22.3	6.2	3.1	1.0	1.3	0.0	0.0	0.0	0.0	0.0
M2H1Z1R2	29.2	3.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R3	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R4	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R5	9.7	3.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z2R1	12.2	9.1	1.5	2.0	2.5	0.0	0.0	0.0	0.0	0.0
M2H1Z2R2	16.3	8.1	2.7	5.4	4.5	0.0	0.0	0.0	0.0	0.0
M2H1Z2R3	15.7	7.1	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z2R4	11.2	9.7	10.2	0.0	0.0	2.9	0.0	0.0	0.0	0.0
M2H1Z2R5	14.5	8.7	7.2	1.9	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R1	11.1	4.3	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R2	14.8	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R3	15.5	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R4	13.5	2.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R5	16.8	10.8	4.9	2.2	0.0	0.0	0.0	0.0	0.0	0.0

M1 = 3 plants/s H1 = 1-cut Z1 = 45 g R1..5 = replication
M2 = 6 plants/s H2 = 2-cut Z2 = 60 g
M3 = 9 plants/s H3 = 3-cut

	Percent of total metering errors									
	Consecutive metering errors									
Trial	1	2	3	4	5	6	7	8	9	10
M2H2Z2R1	16.6	8.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R2	14.0	12.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R3	10.8	6.1	2.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R4	13.7	6.8	1.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R5	16.4	5.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
M2H3Z1R1	8.8	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R2	7.9	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R3	12.7	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R4	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R5	7.1	1.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R1	11.7	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R2	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R3	10.2	7.3	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R4	12.1	5.6	2.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R5	11.6	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R1	21.8	1.4	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R2	28.2	0.0	4.8	0.0	1.1	0.0	0.0	0.0	0.0	0.0
M3H1Z1R3	29.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R4	7.7	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R1	10.7	1.8	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R2	10.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R3	17.0	4.5	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R4	5.4	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R5	11.2	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R1	11.5	3.1	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R2	13.1	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R3	6.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R4	5.5	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R5	13.0	5.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R1	15.5	1.7	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R2	9.2	1.9	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R3	15.6	5.4	2.7	0.0	2.2	0.0	0.0	0.0	0.0	0.0
M3H2Z2R4	13.8	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R5	19.6	5.5	1.2	0.0	0.0	0.0	2.7	0.0	0.0	0.0
M3H3Z1R1	7.3	1.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R2	6.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R3	7.9	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R4	9.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R5	4.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z2R1	9.7	3.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z2R2	11.7	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z2R3	10.9	7.8	2.3	3.1	3.9	0.0	0.0	0.0	0.0	0.0
M3H3Z2R4	7.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z2R5	6.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

M1 = 3 plants/s H1 = 1-cut Z1 = 45 g R1..5 = replication
M2 = 6 plants/s H2 = 2-cut Z2 = 60 g
M3 = 9 plants/s H3 = 3-cut

B4. Whole seed-metering trial data listed below represents the distribution of consecutive metering errors expressed as a percent of total metering errors.

	Percent of total metering errors									
	Consecutive metering errors									
Trial	1	2	3	4	5	6	7	8	9	10
M1HOR1	11.8	17.0	13.7	5.2	3.3	3.9	0.0	0.0	0.0	0.0
M1HOR2	8.2	10.6	8.8	14.1	0.0	10.6	0.0	0.0	5.3	0.0
M1HOR3	12.4	12.9	12.4	4.7	5.9	7.1	0.0	0.0	0.0	0.0
M1HOR4	10.9	10.9	8.2	5.4	6.8	0.0	0.0	5.4	0.0	0.0
M1HOR5	12.6	11.0	1.7	15.4	5.5	3.3	3.8	0.0	0.0	0.0
M2HOR1	16.4	6.9	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2HOR2	14.6	10.1	8.4	2.3	0.0	0.0	0.0	0.0	0.0	0.0
M2HOR3	14.9	8.3	3.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0
M2HOR4	15.5	3.7	3.7	0.0	3.1	0.0	0.0	0.0	0.0	0.0
M2HOR5	12.6	6.6	3.3	8.8	0.0	0.0	0.0	0.0	0.0	0.0
M3HOR1	14.3	1.5	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3HOR2	13.2	2.4	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3HOR3	8.1	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3HOR4	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3HOR5	8.8	2.8	1.6	1.4	0.9	1.1	0.0	0.0	0.0	0.0

M1 = 3 plants/s HO = whole seed R1..5 = replication
M2 = 6 plants/s
M3 = 9 plants/s

10. APPENDIX C. MONITOR COMPONENTS

Potato Planter Monitor Components

Name	Description	Code	Number	Purpose
Components for the microprocessor board				
M6809	8-BIT Micro-processor	U1	1	MPU - executes M6809 instruction set
741s245N	Octal bus transceivers	U2	1	Buffers for data lines
74LS244	Octal buffer line drivers /receivers	U3-U5	3	Buffers for address and control lines
74154N	4-line to 16-line de-multiplexer	U7	1	Facilitates division of addressable memory into 16 - 4K memory blocks
2716JL	2048 word x 8 bit erasable prom	U8,U9	2	Provides one 2K reprogrammable ROM
6116P	2048 word x 8 bit high speed static CMOS RAM	U11	1	Random access memory for program variables, and system stacks (2K)
MC6850	ACIA	U13,U14	2	Facilitates serial communications
MC6821P	PIA	U19	1	Facilitates physical-logical interface with peripheral devices
MC6840	PTM	U15	1	Provides 3 programable timers, used for 5 s statistical and display updates
7400N	Quad 2 input NAND gates	U10	1	NAND logic function decoding
74LS02	Quad 2 input NOR gates	U12	1	Allows for 2 of 4 decoding
7404N	Hex inverter	U29	1	Inverts logic signals
7408N	Quad 2 input AND gates	U30	1	Row change request circuit

cont...

Monitor Components (cont...)

Name	Description	Code	Number	Purpose
7414N	Hex Schmitt-trigger inverters	U6	1	
Crystal				
MP0368	3.57 MHz crystal	C1	1	Provides input signal for M6809 clock signal (E and Q)
Capacitors				
150 uF	Incoming end of Vcc and Gnd bars		1	Smooths power supply
27 pF	In crystal circuit	C1	2	Sine wave O/P
10.0 uF	Between Vcc and GND bars		9	Decoupling
1.0 uF	In reset circuit	R1	1	Switch debouncing
2.4 nF	Row change	R4	1	Switch debouncing
Resistors				
1 kΩ	1/4 W	R2-R4	17	Pull-up resistors in microswitch and photoscanner circuit, row select debouncing
2.7 kΩ	1/4 W	R4	1	Row select switch debouncing
4.7 kΩ	1/4 W	R1,R5	6	Pullup resistors for IRQ, FIRQ, HALT, NMI, BMA/BREQ, MRDY, on MPU and row select circuit
10 kΩ	1/4 W	R1,R5 R4	17	Debouncing circuit, crystal circuit, and PTM to Gnd circuit

cont...

Monitor Components (cont...)

Name	Description	Code Number	Purpose
Input devices			
Micro-switches	8 bit micro switch	S2,S3 2	Allows input of number of rows and number of elements/row for the planter
Pulse switches	Normally open	S1,S4 S5 3	Reset and display mode change, row change
Toggle switches	on-off	S6,S7 2	Used to enable row autoincrement function and defective element indicator (buzzer)
Output devices			
PCIM200	PCI alphanumeric LCD dot matrix module	T9 1	Facilitates the display of performance information
Buzzer	Small Radio Shack buzzer	T10 1	Indicates defective metering element
Connectors			
D9	9 pin male	D9 1	Serial communication port
40 pin	Right angle ~~male,~~ board mount	U22,U23 2	Microprocessor board to monitor connection
40 pin	Ribbon clamp female	U22,U23 2	Microprocessor board to monitor connection
16 pin	Male IC ribbon connector	J4	Sensor connection to microprocessor board
IC Sockets			
	40 pins	U1,U16 U19 3	MPU, PIA socket

cont...

Monitor Components (cont...)

Name	Description	Code Number	Purpose
	28 pins	U15 1	PTM socket
	24 pins	U7 U8 U9 U11 U13,U14 6	Demultiplexer socket EPROM socket EPROM socket RAM socket ACIA (x 2) sockets
	20 pins	U2-U5 4	Buffer sockets
	16 pins	R1-R5 5	ICs and resistor bank sockets
	14 pins	R1,U6 U10,U12 U17 5	ICs and resistor banks sockets
Misc.			
Board	Perforated IC board	2	For microprocessor system and display
Board stand	Al board holder with legs top and bottom	1	Allow for circuit assembly and provides
Wire wrap wire	Plastic coated	Fair bit	Connections between socket pins
Ribbon wire	40 pin	30 cm	Connects main board to display board
	16 pin	130 cm	Connects sensors to main board
Power cord	With banana plugs	2	Vcc and Gnd connection

cont...

Monitor Components (cont...)

Name	Description	Code Number	Purpose
Components for each row monitored			
MC6821P	PIA	U16 1	Facilitates physical-logical interface with peripheral devices
Inverters (7404N)	2 Input inverter gates	U29 6	Used to generate logic level O/P from 'Hall Effect' sensor
Drivers (7407N)	Hex buffer/drivers with open collector high voltage O/P gates	U20,U21 8	Drives LEDs and buzzer
NAND gates (7400N)	2 Input NAND gates	U17 2	Used to generate logic level O/P from photoscanner
Input devices			
MCS-651 (Wanner Electric)	Modulated IR through beam photoscanner	N1 1	Potato sensor
UGS3019T	Sprague 'Hall Effect' switch	N2 1	Detects occurence of metering event
Output devices			
LEDs	Retangular yellow	L1 4	Indicate consecutive metering misses
	red	L1 2	Indicate sensor malfunction
	green	L1 3	Row display indicator
Resistors			
47Ω	1/4 W	R6 8	Current limiting resistors for LED

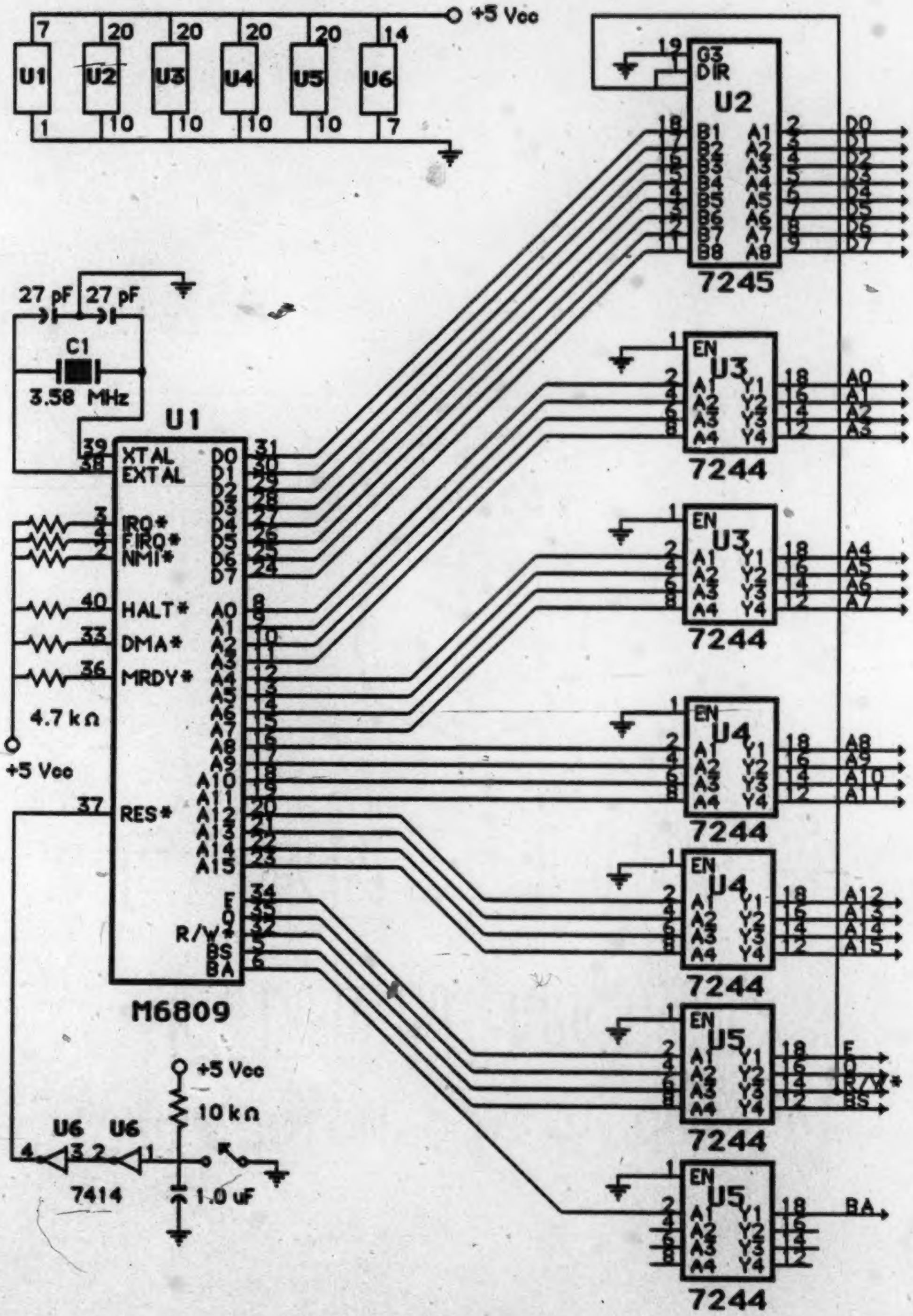
cont...

Monitor Components (cont...)

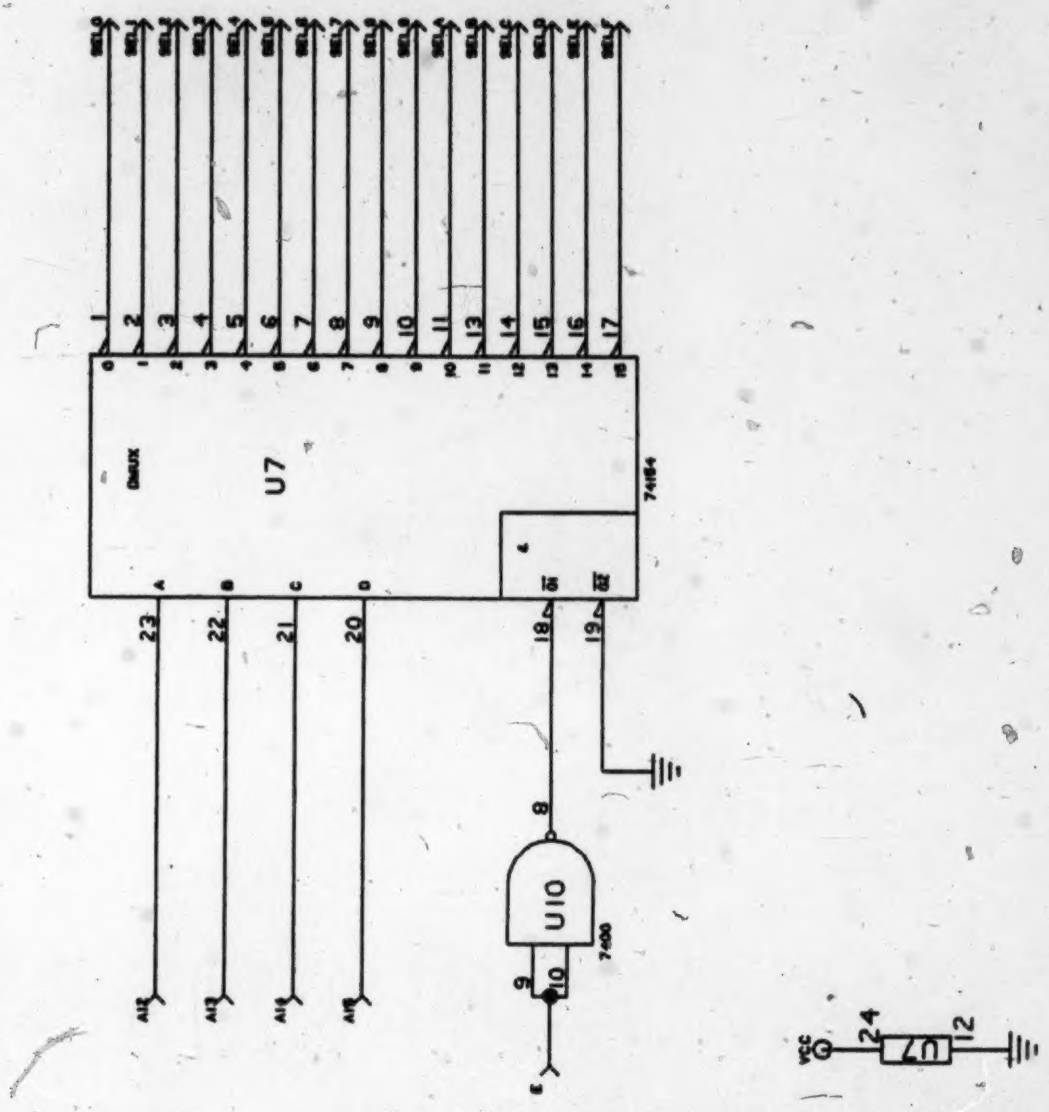
Name	Description	Code Number	Purpose
4.7 kΩ	1/4 W	R5 1	Pullup for IR photo-scanner circuit
Misc.			
Wire wrap wire	Plastic coated	Fair bit	Connections between socket pins
IC Sockets	40 pins	U16 1	PIA socket

11. APPENDIX D. MONITOR CIRCUIT DIAGRAMS

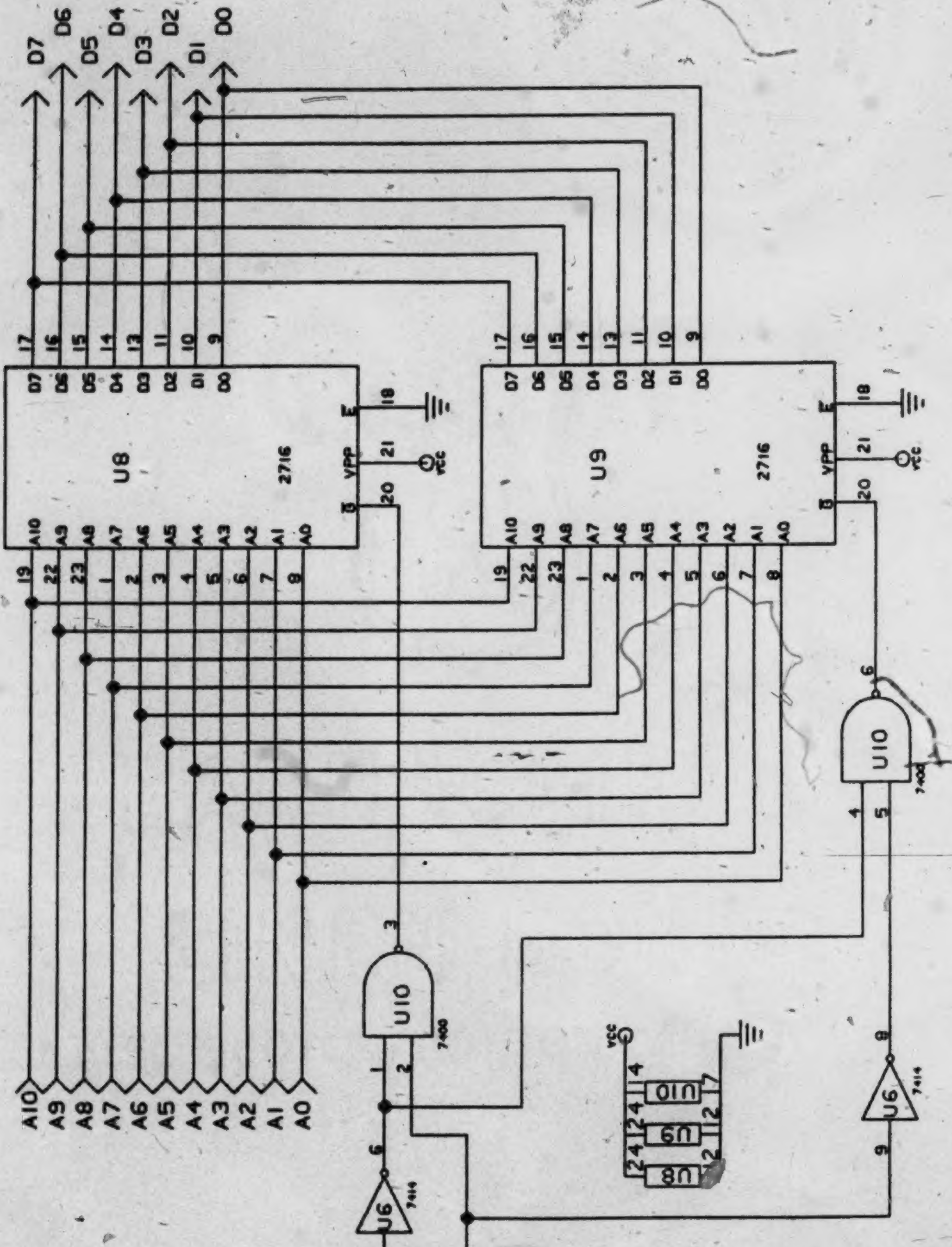
D1. Microprocessor, Clock, and Reset Circuit


+5 Vcc
U1
U2
U3
U4
U5
U6
7
20
20
20
20
14
1
10
10
10
10
7
27 pF
27 pF
C1
3.58 MHz
U1
39
38
XTAL
EXTAL
3
4
2
IRQ*
FIRQ*
NMI*
40
HALT*
33
DMA*
36
MRDY*
4.7 kΩ
+5 Vcc
37
RES*
D0
D1
D2
D3
D4
D5
D6
D7
A0
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
E
Q
R/W*
BS
BA
31
30
29
28
27
26
25
24
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
34
35
32
5
6
M6809
+5 Vcc
10 kΩ
U6
U6
4
3
2
1
7414
1.0 uF
19
1
G3
DIR
U2
B1
B2
B3
B4
B5
B6
B7
B8
A1
A2
A3
A4
A5
A6
A7
A8
18
17
16
15
14
13
12
11
2
3
4
5
6
7
8
9
D0
D1
D2
D3
D4
D5
D6
D7
7245
EN
U3
A1
A2
A3
A4
Y1
Y2
Y3
Y4
1
2
4
6
8
18
16
14
12
A0
A1
A2
A3
7244
EN
U3
A4
A5
A6
A7
7244
EN
U4
A8
A9
A10
A11
7244
EN
U4
A12
A13
A14
A15
7244
EN
U5
E
Q
R/W*
BS
7244
EN
U5
BA
7244

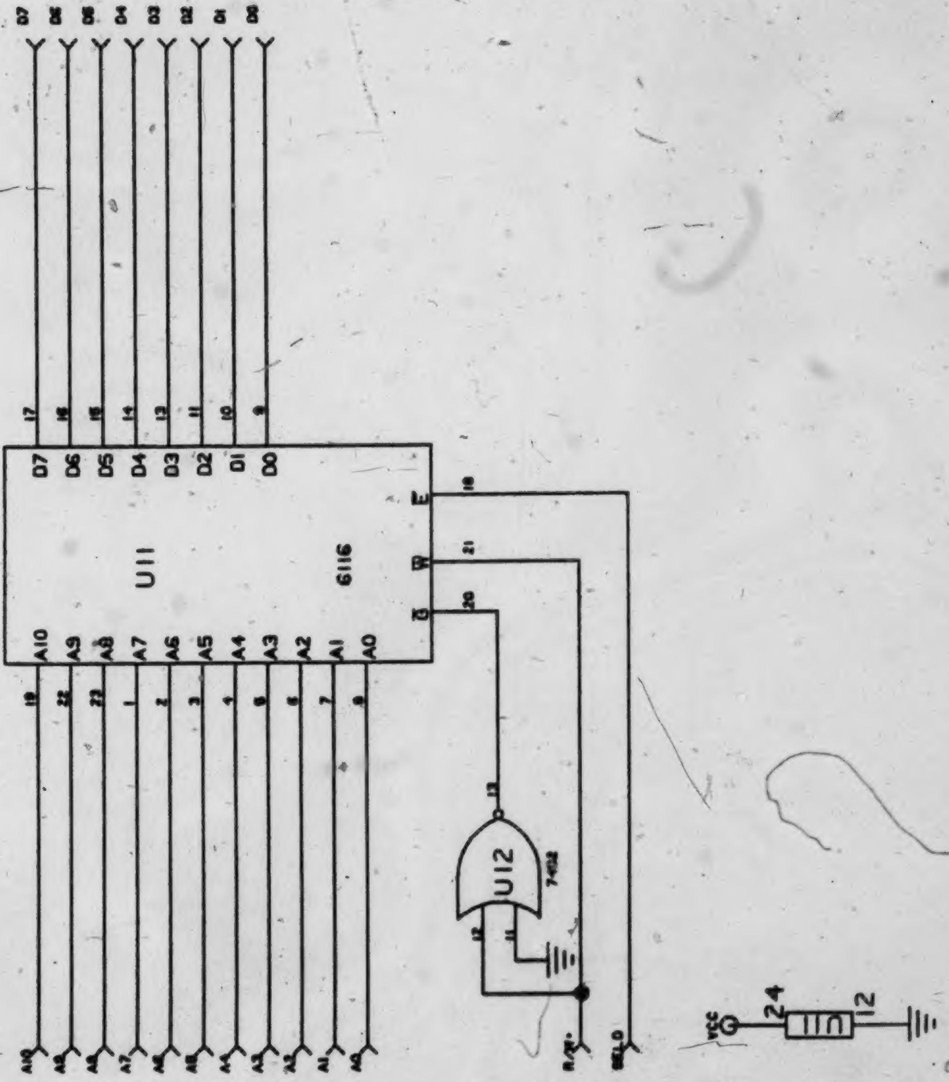
D2. Address Decoding Circuit


U7
DMUX
74154
A
B
C
D
&
G1
G2
23
22
21
20
18
19
1
2
3
4
5
6
7
8
9
10
11
13
14
15
16
17
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
8
9
10
U10
7400
A12
A13
A14
A15
E
VCC
24
U7
12

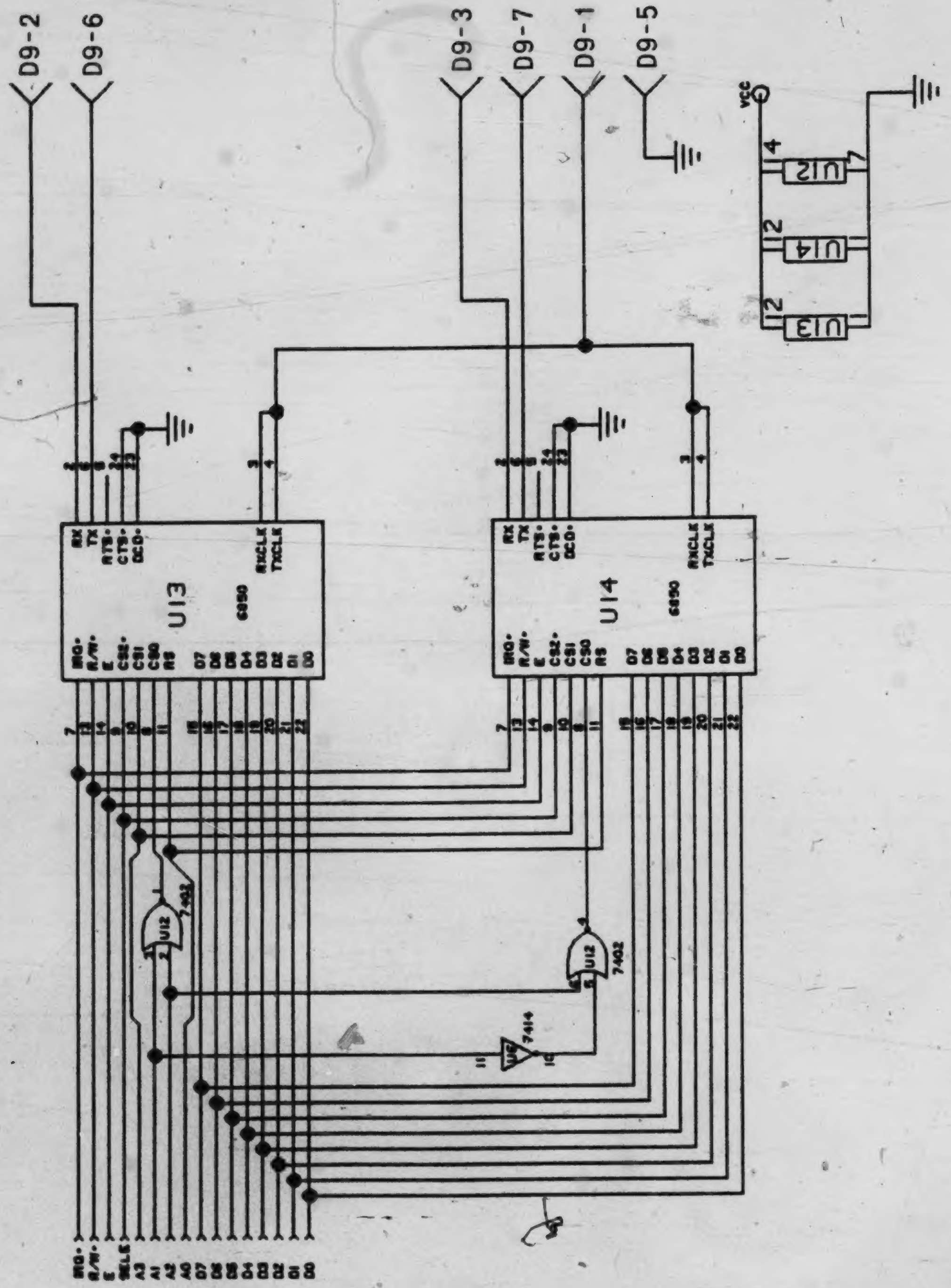
D3. EPROM Circuit —


D7
D6
D5
D4
D3
D2
D1
D0
U8
U9
2716
VPP
VCC
E
G
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
A0
U10
7400
U6
7414
F
I

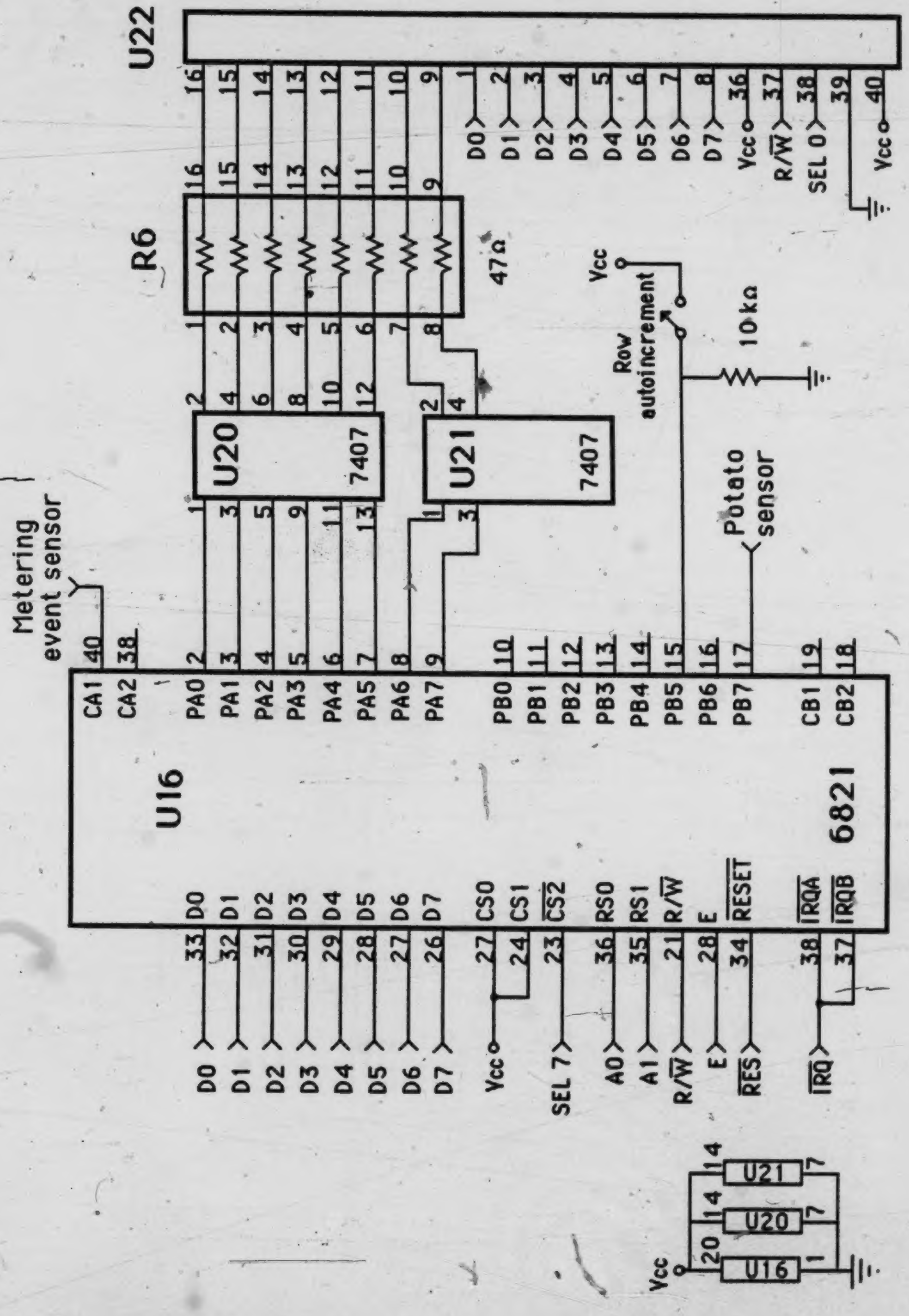
D4. RAM Circuit


D7
D6
D5
D4
D3
D2
D1
D0
17
16
15
14
13
11
10
9
U11
6116
E
W
G
18
21
20
A10
A9
A8
A7
A6
A5
A4
A3
A2
A1
A0
19
22
23
1
2
3
4
5
6
7
8
U12
7402
13
12
11
R/W*
SEL0
VCC
24
U11
12

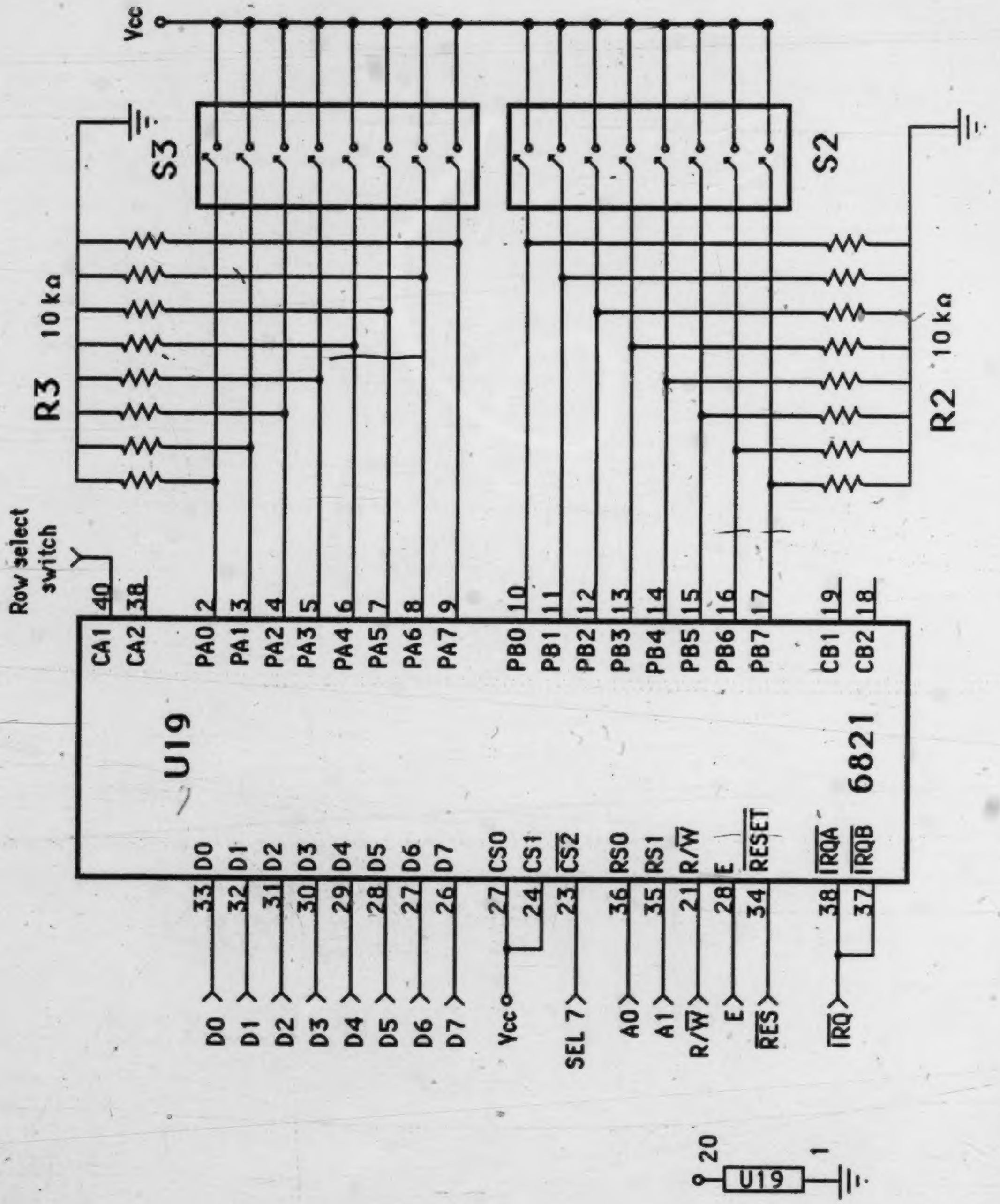
D5. ACIA Circuit


D9-2
D9-6
D9-3
D9-7
D9-1
D9-5
VCC
U12
U14
U13
4
7
2
2
RX
TX
RTS-
CTS-
DCD-
RXCLK
TXCLK
U13
6850
U14
6850
IRQ-
R/W-
E
CS2-
CS1
CS0
RS
D7
D6
D5
D4
D3
D2
D1
D0
U12
7402
U12
7402
U17
7414
A1
A0
D7
D0

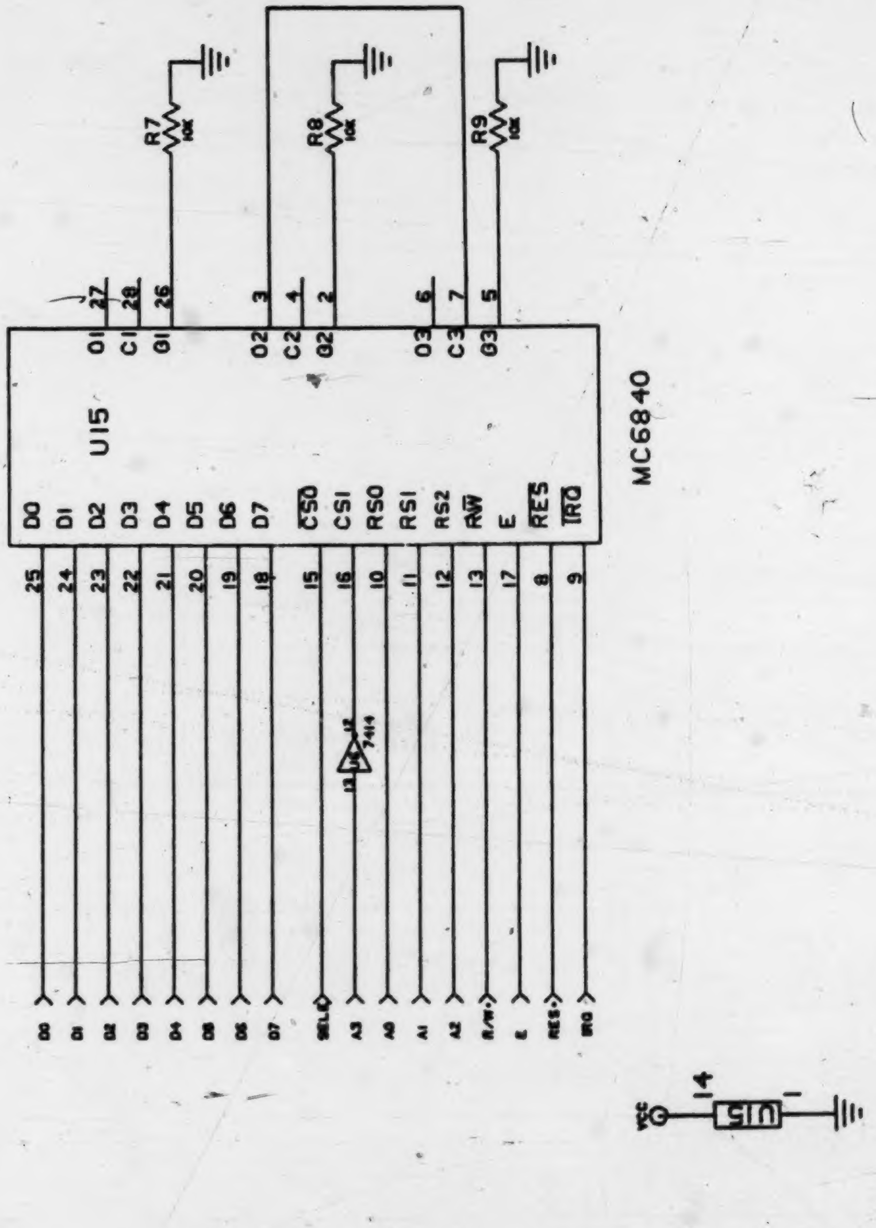
D6. Row PIA Circuit


U22
R6
47Ω
U20
7407
U21
7407
U16
6821
Metering event sensor
Row autoincrement
Vcc
10 kΩ
Potato sensor
CA1
CA2
PA0
PA1
PA2
PA3
PA4
PA5
PA6
PA7
PB0
PB1
PB2
PB3
PB4
PB5
PB6
PB7
CB1
CB2
D0
D1
D2
D3
D4
D5
D6
D7
CS0
CS1
CS2
RS0
RS1
R/W
E
RESET
IRQA
IRQB
Vcc
SEL 7
A0
A1
R/W
E
RES
IRQ
Vcc
R/W
SEL 0
Vcc
U21
U20
U16
20
14
14
7
7
1

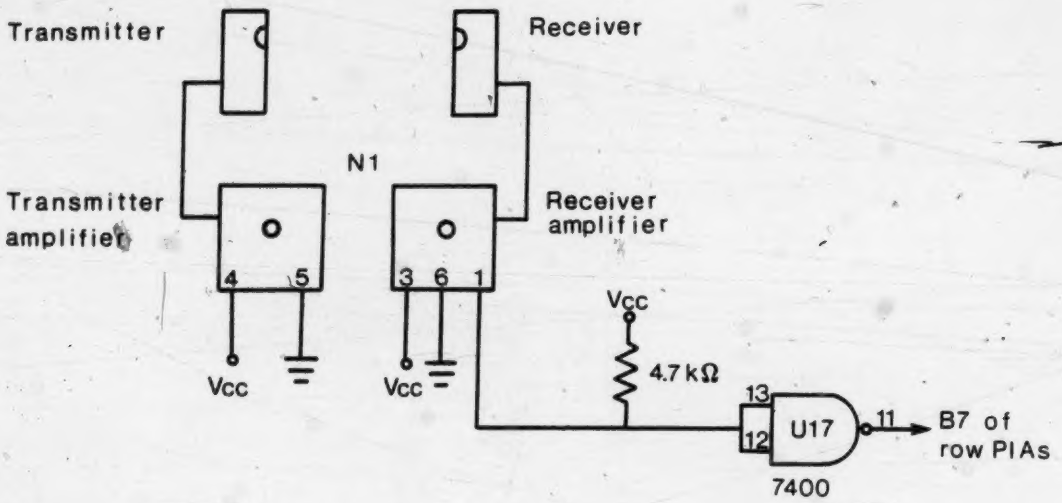
D7. Microswitch PIA Circuit


Vcc
S3
S2
R3
10 kΩ
R2
10 kΩ
Row select switch
U19
6821
CA1 40
CA2 38
PA0 2
PA1 3
PA2 4
PA3 5
PA4 6
PA5 7
PA6 8
PA7 9
PB0 10
PB1 11
PB2 12
PB3 13
PB4 14
PB5 15
PB6 16
PB7 17
CB1 19
CB2 18
D0 33
D1 32
D2 31
D3 30
D4 29
D5 28
D6 27
D7 26
CS0 27
CS1 24
CS2 23
RS0 36
RS1 35
R/W 21
E 28
RESET 34
IRQA 38
IRQB 37
D0
D1
D2
D3
D4
D5
D6
D7
Vcc
SEL 7
A0
A1
R/W
E
RES
IRQ
20
U19
1

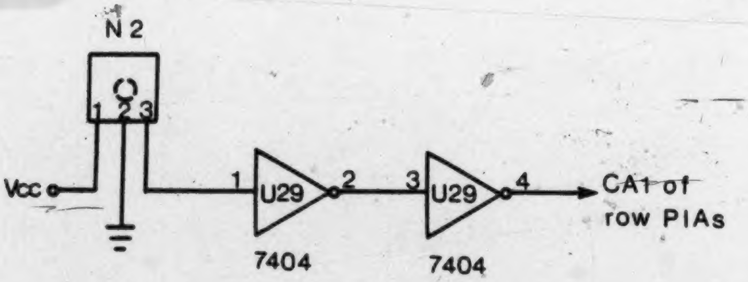
D8. PTM Circuit


U15
MC6840
R7
10K
R8
10K
R9
10K
O1
C1
G1
O2
C2
G2
O3
C3
G3
27
28
26
3
4
2
6
7
5
D0
D1
D2
D3
D4
D5
D6
D7
CS0
CS1
RS0
RS1
RS2
R/W
E
RES
IRQ
25
24
23
22
21
20
19
18
15
16
10
11
12
13
17
8
9
7414
13
12
D0
D1
D2
D3
D4
D5
D6
D7
SELE
A3
A0
A1
A2
R/W-
E
RES-
IRQ
VCC
14
7
U15

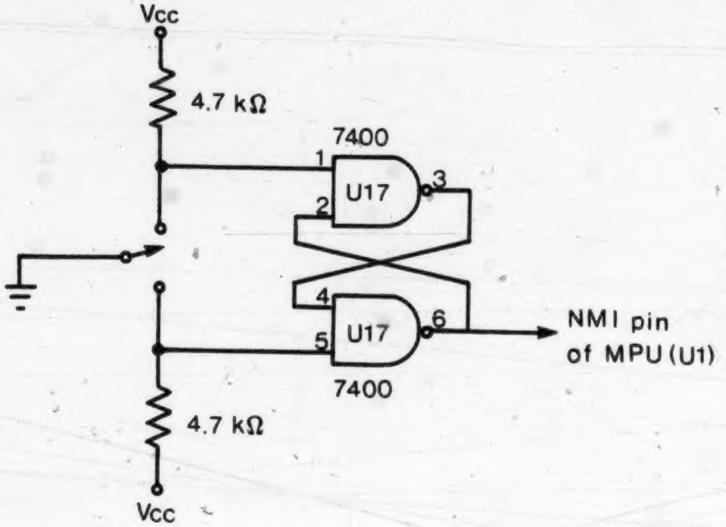
D9. Potato Sensor


Transmitter
Receiver
N1
Transmitter amplifier
Receiver amplifier
4
5
3
6
1
Vcc
Vcc
Vcc
4.7 kΩ
13
12
U17
11
B7 of row PIAs
7400

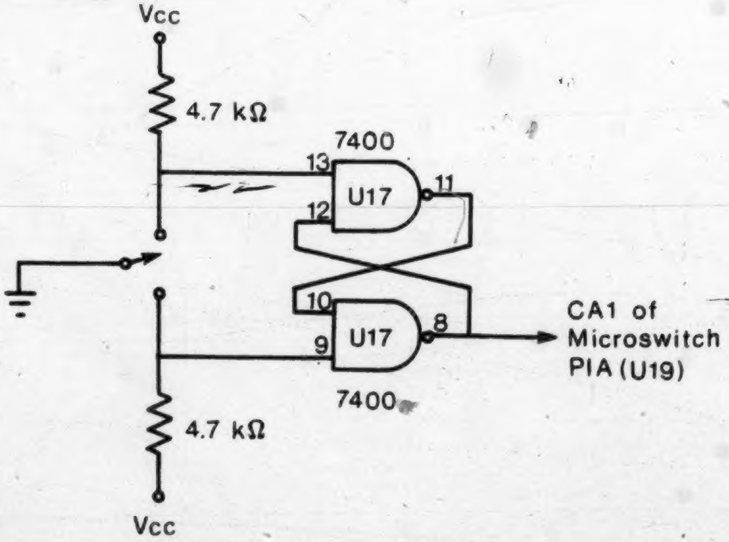
D10. Metering Event Sensor


N 2
1
2
3
Vcc
1
U29
2
3
U29
4
CA1 of row PIAs
7404
7404

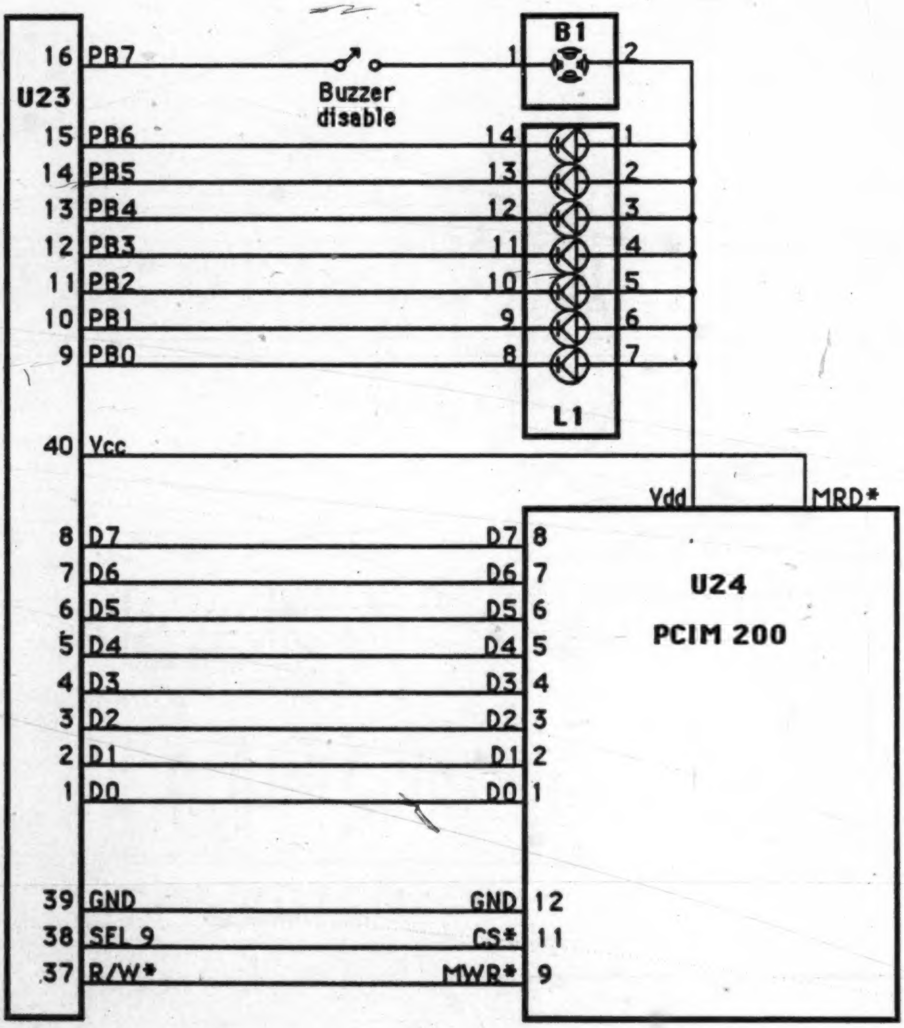
D11. Mode Change Circuit


Vcc
4.7 kΩ
7400
1
2
3
U17
4
5
6
U17
7400
NMI pin
of MPU (U1)
4.7 kΩ
Vcc

D12. Row Change Circuit


Vcc
4.7 kΩ
7400
13
12
11
U17
10
9
8
U17
7400
CA1 of
Microswitch
PIA (U19)
4.7 kΩ
Vcc

D13. Display Circuit


U23
16 PB7
15 PB6
14 PB5
13 PB4
12 PB3
11 PB2
10 PB1
9 PB0
40 Vcc
8 D7
7 D6
6 D5
5 D4
4 D3
3 D2
2 D1
1 D0
39 GND
38 SEL 9
37 R/W*
Buzzer
disable
B1
1
2
L1
14
13
12
11
10
9
8
1
2
3
4
5
6
7
Vdd
MRD*
U24
PCIM 200
D7 8
D6 7
D5 6
D4 5
D3 4
D2 3
D1 2
D0 1
GND 12
CS* 11
MWR* 9

12. APPENDIX E. MONITOR PROGRAM

```
PPM  ;(Potato planter monitor)                                                  M6809 Version UL202    Page    1

ILC  Object       I  STMT   Line #    Source Statement                                                17:33:32  06-27-86
                        1       1.           NAM  PPM   ;Potato Planter Monitor
                        2       2.    * PROGRAM NAME:    PPM.M69
                        3       3.    * PURPOSE:         Potato Planter Performance Feedback
                        4       4.    * PROGRAMED FOR:   Partial fulfillment of Masters thesis project
                        5       5.    * DESIGNED FOR:    M6809 microprocessor
                        6       6.    * DATE COMPLETED:  June 27, 1986.
                        7       7.    * PROGRAMER:       Edward Hauck
                        8       8.    *<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
                        9       9.    *
                       10      10.    *
                       11      11.    * Routine addresses *
                       12      12.    *
     F800              13      13.    RESET  EQU  $F800    ;Reset
     F960              14      14.    IRQ    EQU  $F960    ;IRQ - metering & statistics update, and row change
     FC00              15      15.    NMI    EQU  $FC00    ;NMI - change modes & display
                       16      16.    *
                       17      17.    * Device addresses *
                       18      18.    *
     0000              19      19.    LCD    EQU  $0000    ;LCD address
     1000              20      20.    PIA1   EQU  $1000    ;Row 1 PIA
     2000              21      21.    PIA2   EQU  $2000    ;Row 2 PIA
     3000              22      22.    PIA3   EQU  $3000    ;Row 3 PIA
     4000              23      23.    PIA4   EQU  $4000    ;Row 4 PIA
     5000              24      24.    PIA5   EQU  $5000    ;Row 5 PIA
     6000              25      25.    PIA6   EQU  $6000    ;Row 6 PIA
     7000              26      26.    PIAS   EQU  $7000    ;Microswitch PIA
                       27      27.    * Timers
     8000              28      28.    PTM1   EQU  $8000    ;PTM 1 (display refresh - clocks  2 & 3; clock 1 unused)
     8002              29      29.    COUNT1 EQU  $8002    ;Counter 1
     8004              30      30.    COUNT2 EQU  $8004    ;Counter 2
     8006              31      31.    COUNT3 EQU  $8006    ;Counter 3
     8003              32      32.    LATCH1 EQU  $8003    ;Latch 1
     8005              33      33.    LATCH2 EQU  $8005    ;Latch 2
     8007              34      34.    LATCH3 EQU  $8007    ;Latch 3
                       35      35.    *
                       36      36.    * Variable addresses (RAM) and variable definitions *
                       37      37.    *
     D000              38      38.    DIVWS  EQU  $D000    ;(3)  Division workspace base address
     D003              39      39.    CNTR1  EQU  $D003    ;(1)  Counter used in division subroutine
     D004              40      40.    NOROWS EQU  $D004    ;(1)  Number of rows
     D005              41      41.    ELOFFS EQU  $D005    ;(1)  Offset to consecutive miss count for first element
     D006              42      42.    LASVAL EQU  $D006    ;(2)  Last value displayed
     D008              43      43.    MODE   EQU  $D008    ;(1)  Display mode
     D009              44      44.    CNTR   EQU  $D009    ;(5)  Counter used in HEX to ASCII conversion
     D00F              45      45.    ZFLG   EQU  $D00F    ;(1)  Flag to keep track of leading zeros
     D010              46      46.    DISROW EQU  $D010    ;(2)  Data block address of row displayed
     D012              47      47.    CURROW EQU  $D012    ;(1)  Row number currently being displayed
     D013              48      48.    AUTORW EQU  $D013    ;(1)  Mode 1 row autoincrement flag
     D014              49      49.    DISLAB EQU  $D014    ;(2)  Address of mode label currently dislayed
     D016              50      50.    OFFSET EQU  $D016    ;(1)  Offset from data block base address of the displayed value
     D017              51      51.    CURPIA EQU  $D017    ;(2)  PIA corresponding to row displayed
     D019              52      52.    LKDAT1 EQU  $D019    ;(2)  Row 1 - Pointer to data block checked on a
     D01B              53      53.    LKDAT2 EQU  $D01B    ;(2)  Row 2   potato sensor malfunction test
     D01D              54      54.    LKDAT3 EQU  $D01D    ;(2)  Row 3
     D01F              55      55.    LKDAT4 EQU  $D01F    ;(2)  Row 4
```

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ILC  Object        I  STMT   Line #   Source Statement

          D021          56      56.   LKDAT5 EQU  $D021    ;(2)  Row 5
          D023          57      57.   LKDAT6 EQU  $D023    ;(2)  Row 6
          D025          58      58.   LKPIA1 EQU  $D025    ;(2)  Row 1 - Pointer to PIA checked on a potato sensor
          D027          59      59.   LKPIA2 EQU  $D027    ;(2)  Row 2   malfunction test
          D029          60      60.   LKPIA3 EQU  $D029    ;(2)  Row 3
          D02B          61      61.   LKPIA4 EQU  $D02B    ;(2)  Row 4
          D02D          62      62.   LKPIA5 EQU  $D02D    ;(2)  Row 5
          D02F          63      63.   LKPIA6 EQU  $D02F    ;(2)  Row 6
          D031          64      64.   VALUE  EQU  $D031    ;(7)  ASCII representation of value displayed
          D039          65      65.   BUZFLG EQU  $D039    ;(1)  Buzzer flag
          D03A          66      66.   MODFLG EQU  $D03A    ;(1)  Mode change flag
          D100          67      67.   DATA1  EQU  $D100    ;(100) Data block 1 base address
          D200          68      68.   DATA2  EQU  $D200    ;(100) Data block 2 base address
          D300          69      69.   DATA3  EQU  $D300    ;(100) Data block 3 base address
          D400          70      70.   DATA4  EQU  $D400    ;(100) Data block 4 base address
          D500          71      71.   DATA5  EQU  $D500    ;(100) Data block 5 base address
          D600          72      72.   DATA6  EQU  $D600    ;(100) Data block 6 base address
          D740          73      73.   USTACK EQU  $D740    ;(40)  User stack pointer
          D800          74      74.   SSTACK EQU  $D800    ;(80)  System stack pointer
                        75      75.   *
                        76      76.   * Program variable offset from data block base addresses for rows 1 to 6 *
                        77      77.   *
          0000          78      78.   CNEV   EQU  $00      ;(1)  Current number of events
          0001          79      79.   CNMISS EQU  $01      ;(1)  Current number of misses
          0002          80      80.   MISLED EQU  $02      ;(1)  Consecutive miss count displayed (yellow LEDs)
          0003          81      81.   LEDDIS EQU  $03      ;(1)  LED display mask
          0004          82      82.   NEXTEL EQU  $04      ;(1)  Next element in the metering chain to be monitored
          0005          83      83.   TMIS   EQU  $05      ;(2)  Total number of misses
          0007          84      84.   TEVENT EQU  $07      ;(2)  Total number of events
          0009          85      85.   THITS  EQU  $09      ;(2)  Total successful events
          000B          86      86.   PERMIS EQU  $0B      ;(2)  Current percent misses
          000D          87      87.   PLRATE EQU  $0D      ;(2)  Current planting rate (Potato/min)
          000F          88      88.   SENFLG EQU  $0F      ;(1)  Flag for potato sensor check
          0010          89      89.   CONMIS EQU  $10      ;(1)  Number of consecutive misses
                        90      90.   *
                        91      91.   *
                        92      92.   *
                        93      93.   * <<<< Initialization routine >>>>
                        94      94.   *
                        95      95.   *  << Initialize stacks >>
                        96      96.   *
F800                    97      97.          ORG  RESET
F800 10CE D800    4     98      98.   STKINT LDS  #SSTACK        ;Ldad system stack
F804 CE   D740    3     99      99.          LDU  #USTACK        ;Load user stack
                       100     100.   *
                       101     101.   *  << Initialization of LCD display >>
                       102     102.   *
F807 BD   FD59    8    103     103.   LCDINT JSR  DELAY          ;Delay to latch character to display
F80A 8E   FDD2    3    104     104.          LDX  #FLAGS         ;Base address of LCD initialization flags
F80D A6   80      6    105     105.   FLGDSP LDA  ,X+            ;Next flag loaded
F80F 97   00      4    106     106.          STA  LCD            ;  and stored
F811 81   8A      2    107     107.          CMPA #$8A           ;Last flag?
F813 26   F8      3    108     108.          BNE  FLGDSP         ;No, get next one
F815 BD   FD4E    8    109     109.          JSR  CLRLCD         ;Clear display
                       110     110.   *
```

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PPM  ;(Potato planter monitor)                                                      M6809 Version UL202    Page    3
                                                                                    17:33:32  06-27-86
ILC  Object        I  STMT   Line #   Source Statement

                          111    111.   *  Display greeting message
F818 8E   FD90     3      112    112.          LDX  #HELFLG        ;Base address for initial message
F81B C6   10       2      113    113.          LDB  #16            ;Number of characters to dump
F81D BD   FD65     8      114    114.          JSR  DUMP           ;Transfer character string from RAM to display buffer
                          115    115.   *
                          116    116.   *  << PIA RESET >>
                          117    117.   *
                          118    118.   *  Reset microswitch PIA
F820 4F            2      119    119.   PIAINT CLRA
F821 B7   7001     5      120    120.          STA  PIAS+1         ;CRA - Access data direction register on A port
F824 B7   7003     5      121    121.          STA  PIAS+3         ;CRB - Access data direction register on B port
F827 B7   7000     5      122    122.          STA  PIAS           ;Port A for input
F82A B7   7002     5      123    123.          STA  PIAS+2         ;Port B for output
F82D 86   05       2      124    124.          LDA  #%00000101
F82F B7   7001     5      125    125.          STA  PIAS+1         ;Access data registers and enable CA1 (port A)
F832 86   04       2      126    126.          LDA  #%00000100
F834 B7   7003     5      127    127.          STA  PIAS+3         ;Access data registers (port B)
                          128    128.   *
                          129    129.   *  PIAs corresponding to each row are initialized
F837 8E   1000     3      130    130.          LDX  #PIA1          ;Start with row 1
F83A F6   7000     5      131    131.          LDB  PIAS           ;Read microswitch for number of rows
F83D C4   BF       2      132    132.          ANDB #%10111111     ;Mask bit-6 setting (Row autoincrement input)
F83F 4F            2      133    133.   PIARES CLRA
F840 A7   01       5      134    134.          STA  1,X            ;CRA - Access data direction register on A port
F842 A7   03       5      135    135.          STA  3,X            ;CRB - Access data direction register on B port
F844 A7   84       4      136    136.          STA  ,X             ;Port A for input
F846 86   FF       2      137    137.          LDA  #%11111111
F848 A7   02       5      138    138.          STA  2,X            ;Port B for input
F84A 86   05       2      139    139.          LDA  #%00000101
F84C A7   01       5      140    140.          STA  1,X            ;Access data registers and enable CA1 (port A)
F84E 86   04       2      141    141.          LDA  #%00000100
F850 A7   03       5      142    142.          STA  3,X            ;Access data registers (port B)
F852 86   DF       2      143    143.          LDA  #%11011111
F854 A7   02       5      144    144.          STA  2,X            ;Turn off all but row select LEDs (green)
F856 30   89 1000  8      145    145.          LEAX $1000,X        ;Base address of next PIA
F85A 5A            2      146    146.          DECB                ;Last PIA?
F85B 26   E2       3      147    147.          BNE  PIARES         ;No, initialize next PIA
                          148    148.   *
                          149    149.   *
                          150    150.   *  << Initialize memory locations in RAM >>
                          151    151.   *
                          152    152.   *  Zero 2K memory at D000-D7FF
F85D 8E   D000     3      153    153.   MEMINT LDX  #$D000         ;Starting at RAM address
F860 6F   80       8      154    154.   NCLR1  CLR  ,X+            ;Clear each byte
F862 8C   D7FF     4      155    155.          CMPX #$D7FF         ;End of RAM?
F865 26   F9       3      156    156.          BNE  NCLR1          ;No, continue
                          157    157.   *
                          158    158.   *  Initialize program variables
F867 8E   D100     3      159    159.          LDX  #DATA1         ;Base addreess of row 1 data block
F86A BF   D010     6      160    160.          STX  DISROW         ;Row 1 is first data block to be displayed
F86D 8E   1000     3      161    161.          LDX  #PIA1
F870 BF   D017     6      162    162.          STX  CURPIA         ;PIA1 corresponds to first data block displayed
F873 8E   FDA0     3      163    163.          LDX  #PMISAS
F876 BF   D014     6      164    164.          STX  DISLAB         ;Address of current mode label
F879 7F   D006     7      165    165.          CLR  LASVAL         ;Last value displayed
```

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ILC  Object        I  STMT   Line #   Source Statement

F87C 86    01      2  166     166.           LDA   #01
F87E B7    D013    5  167     167.           STA   AUTORW         ;Mode 1 row autoincrement flag is set (disabled)
F881 B7    D012    5  168     168.           STA   CURROW         ;Number of data block currently displayed
F884 C6    08      2  169     169.           LDB   #PERMIS
F886 F7    D016    5  170     170.           STB   OFFSET         ;Offset from data block base of variable displayed
F889 86    DF      2  171     171.           LDA   #%11011111
F88B B7    D103    5  172     172.           STA   DATA1+LEDDIS   ;Row select bit (B6) in LED display mask on
F88E 86    FF      2  173     173.           LDA   #$FF
F890 B7    D203    5  174     174.           STA   DATA2+LEDDIS   ;Remaining LED display masks initialized to off
F893 B7    D303    5  175     175.           STA   DATA3+LEDDIS
F896 B7    D403    5  176     176.           STA   DATA4+LEDDIS
F899 B7    D503    5  177     177.           STA   DATA5+LEDDIS
F89C B7    D603    5  178     178.           STA   DATA6+LEDDIS
                      179     179.   *
                      180     180.   *  Read microswitches
                      181     181.   *    Port A - number of rows
                      182     182.   *    Port B - number of elements in each row of the metering device
F89F B6    7000    5  183     183.           LDA   PIAS           ;Read number of rows
F8A2 84    BF      2  184     184.           ANDA #%10111111      ;Bit-6 s masked out (mode 1 autoincrement input)
F8A4 B7    D004    5  185     185.           STA   NOROWS
F8A7 F6    7002    5  186     186.           LDB   PIAS+2         ;Read number of metering elements in each row
F8AA CB    11      2  187     187.           ADDB #$11            ;Add offset to next available memory for each block
F8AC F7    D005    5  188     188.           STB   ELOFFS         ;Memory offset to element missing flags
F8AF 8E    D100    3  189     189.           LDX   #DATA1         ;Base address of first data block
F8B2 E7    04      5  190     190.   OFFINT  STB   NEXTEL,X       ;Offset pointer current element in metering chain
F8B4 30    89 0100 8  191     191.           LEAX $0100,X         ;Base address of next data block
F8B8 4A            2  192     192.           DECA
F8B9 26    F7      3  193     193.           BNE   OFFINT         ;Last data block? If not initialize next data block
                      194     194.   *
                      195     195.   *  Potato sensor malfunction test checks sensor corresponding to PIA furthest
                      196     196.   *    away from interrupting PIA. Pointers to data blocks and PIA checked on
                      197     197.   *    an event are initialized for each row.
F8BB 108E  FD7A    4  198     198.           LDY   #CKDAT         ;Base address for data blocks base addesses used in
F8BF B6    D004    5  199     199.           LDA   NOROWS         ;  light sensor malfunction tests
F8C2 1F    89      7  200     200.           TFR   A,B
F8C4 80    02      2  201     201.           SUBA #02             ;Offset to address of data block checked on row 1
F8C6 AE    A6      6  202     202.           LDX   A,Y            ;  interrupt
F8C8 8B    02      2  203     203.           ADDA #02             ;Number of rows
F8CA 44            2  204     204.           LSRA                 ;Number of row/2
F8CB 108E  D019    4  205     205.           LDY   #LKDAT1        ;Pointer to data block checked on row 1 interrupt
F8CF AF    A1      8  206     206.   LKDAT   STX   ,Y++           ;Pointer to data block correspnding to row checked
F8D1 5A            2  207     207.           DECB                 ;All data blocks initialized?
F8D2 27    12      3  208     208.           BEQ   SETPIA         ;Yes, Initialize PIA pointers
F8D4 4A            2  209     209.           DECA
F8D5 B1    D004    5  210     210.           CMPA NOROWS          ;Last row initialised?
F8D8 26    06      3  211     211.           BNE   INCDAT         ;No, continue to next highest data block
F8DA 8E    D000    3  212     212.           LDX   #$D000         ;Reinitialize X register for next data block pointer
F8DD B6    D004    5  213     213.           LDA   NOROWS
F8E0 30    89 0100 8  214     214.   INCDAT  LEAX $0100,X         ;Pointer to next data block to checked on an event
F8E4 20    E9      3  215     215.           BRA   LKDAT          ;Initialize next data block
                      216     216.   *
F8E6 108E  FD80    4  217     217.   SETPIA  LDY   #CKPIA         ;Base address for PIA pointers used in potato
F8EA B6    D004    5  218     218.           LDA   NOROWS         ;  sensor malfunction tests
F8ED 1F    89      7  219     219.           TFR   A,B
F8EF 80    02      2  220     220.           SUBA #02             ;Offset to address of data block checked on row 1
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ILC  Object        I  STMT   Line #   Source Statement                                                    17:33:32  06-27-86

F8F1 AE   A6       6   221    221.           LDX  A,Y          ;  interrupt
F8F3 8B   02       2   222    222.           ADDA #02          ;Number of rows
F8F5 44            2   223    223.           LSRA              ;Number of row/2
F8F6 108E D025     4   224    224.           LDY  #LKPIA1      ;Pointer to PIA checked on row 1 interrupt
F8FA AF   A1       8   225    225.   LKPIA   STX  ,Y++         ;PIA checked on interrupt from corresponding row
F8FC 5A            2   226    226.           DECB              ;All PIA pointers initialized?
F8FD 27   0F       3   227    227.           BEQ  SETPTM       ;Yes, continue
F8FF 4A            2   228    228.           DECA
F900 26   06       3   229    229.           BNE  INCPIA       ;Last PIA initialized?
F902 8E   0000     3   230    230.           LDX  #$0000       ;Reinitialize PIA pointer address
F905 B6   D004     5   231    231.           LDA  NOROWS
F908 30   89 1000  8   232    232.   INCPIA LEAX $1000,X       ;Pointer to next PIA checked on an event
F90C 20   EC       3   233    233.           BRA  LKPIA        ;Initialize next PIA
                       234    234.   *
                       235    235.   *
                       236    236.   *  << PTM reset >>
                       237    237.   *
                       238    238.   *    Timers 2 and 3 are cascaded together to produce an interrupt every 5 s.
                       239    239.   *
F90E 8E   AE62     3   240    240.   SETPTM LDX  #44642
F911 BF   8004     6   241    241.          STX  COUNT2        ;Set latch 2
F914 8E   0032     3   242    242.          LDX  #50
F917 BF   8006     6   243    243.          STX  COUNT3        ;Set latch 3
F91A 8E   FFFF     3   244    244.          LDX  #65535
F91D BF   8002     6   245    245.          STX  COUNT1        ;Set latch 1
                       246    246.   *
                       247    247.   * Initialize control registers of PTMs
                       248    248.   *   Register 3
F920 86   E0       2   249    249.          LDA  #%11100000    ;B0  :T3 Clock +1
F922 B7   8000     5   250    250.          STA  PTM1          ;B1  :External clock.
                       251    251.   *                         ;B2  :16 Bit operation
                       252    252.   *                         ;B3-5:Continuous mode
                       253    253.   *                         ;B6  :interrupt enabled
                       254    254.   *                         ;B7  :Output enabled
                       255    255.   *
                       256    256.   *   Register 2
F925 86   83       2   257    257.          LDA  #%10000011    ;B0  :Select control register 1
F927 B7   8001     5   258    258.          STA  PTM1+1        ;B1  :Use internal clock
                       259    259.   *                         ;B2  :16 Bit operation
                       260    260.   *                         ;B3-5:Continuous mode
                       261    261.   *                         ;B6  :Mask interrupts
                       262    262.   *                         ;B7  :Output enabled
                       263    263.   *
                       264    264.   *   Register 1
F92A 86   B3       2   265    265.          LDA  #%10110011    ;B0  :All timers preset
F92C B7   8000     5   266    266.          STA  PTM1          ;B1  :Use internal clock
                       267    267.   *                         ;B2  :16 Bit operation
                       268    268.   *                         ;B3-5:Single shot mode
                       269    269.   *                         ;B6  :Enable interrupt
                       270    270.   *                         ;B7  :output enabled
                       271    271.   *
                       272    272.   *
                       273    273.   *
                       274    274.   *  <<<< Main program >>>>
                       275    275.   *
```

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ILC  Object         I  STMT   Line #    Source Statement
F92F 3C    AF      21   276    276.            CWAI #%10101111     ;Stack registers and wait for an interrupt
F931 86    B2       2   277    277.            LDA  #%10110010     ;First metering event just occured
F933 B7    8000     5   278    278.            STA  PTM1           ;Statistics update and display refresh timers operate
                        279    279.     *
                        280    280.     *  Turn off all row select LEDs off execpt row 1.
F936 F6    D004     5   281    281.            LDB  NOROWS
F939 5A             2   282    282.            DECB
F93A 8E    07D0     3   283    283.            LDX  #2000
F93D 86    FF       2   284    284.            LDA  #%11111111
F93F A7    02       5   285    285.     NEXOFF STA  2,X            ;Turn off row select LED
F941 30    89 1000  8   286    286.            LEAX $1000,X
F945 5A             2   287    287.            DECB
F946 26    F7       3   288    288.            BNE  NEXOFF         ;All LEDs off? If not, next one
F948 3C    AF      21   289    289.     LOOP   CWAI #%10101111     ;Stack registers and wait for an interrupt
F94A 20    FC       3   290    290.            BRA  LOOP           ;Wait for another interrupt
                        291    291.     *
                        292    292.     *
                        293    293.     *
                        294    294.     * <<<< IRQ Service routine: Metering & statistics update, and change rows >>>>
                        295    295.     *
                        296    296.     *  << Polling routine >>
                        297    297.     *
F960                    298    298.            ORG  IRQ
                        299    299.     *      ANDCC #%01010000    ;Mask interrupts
                        300    300.     *
                        301    301.     *  Row 1 metering event (event sensor trigger)?
F960 B6    1001     5   302    302.     INT1   LDA  PIA1+1         ;Row 1 polled
F963 2A    1C       3   303    303.            BPL  INT2           ;If no interrupt, check row 2
F965 7D    D10F     7   304    304.            TST  DATA1+SENFLG   ;First interrupt since statistics update?
F968 26    0D       3   305    305.            BNE  INTGO1         ;No, initialize base addresses for metering update
F96A BE    D019     6   306    306.            LDX  LKDAT1         ;Data block base address for malfunction test
F96D 10BE  D025     7   307    307.            LDY  LKPIA1         ;PIA base address for malfunction test
F971 BD    FA3A     8   308    308.            JSR  MALTST         ;Check for potato sensor malfunction
F974 7C    D10F     7   309    309.            INC  DATA1+SENFLG   ;Set flag indicating malfunction test complete
F977 8E    D100     3   310    310.     INTGO1 LDX  #DATA1         ;Base address of row 1 data block
F97A 108E  1000     4   311    311.            LDY  #PIA1          ;Base address of row 1 PIA
F97E 16    00C8     5   312    312.            LBRA METUPD         ;Go to metering update
                        313    313.     *
                        314    314.     *  Row 2 metering event (event sensor trigger)?
F981 B6    2001     5   315    315.     INT2   LDA  PIA2+1         ;Row 2 polled
F984 2A    1C       3   316    316.            BPL  INT3           ;If no interrupt, check row 3
F986 7D    D20F     7   317    317.            TST  DATA2+SENFLG   ;First interrupt since statistics update?
F989 26    0D       3   318    318.            BNE  INTGO2         ;No, initialize base addresses for metering update
F98B BE    D01B     6   319    319.            LDX  LKDAT2         ;Data block base address for malfunction test
F98E 108E  D027     7   320    320.            LDY  LKPIA2         ;PIA base address for malfunction test
F992 BD    FA3A     8   321    321.            JSR  MALTST         ;Check for potato sensor malfunction
F995 7C    D20F     7   322    322.            INC  DATA2+SENFLG   ;Set flag indicating malfunction test complete
F998 8E    D200     3   323    323.     INTGO2 LDX  #DATA2         ;Base address of row 2 data block
F99B 108E  2000     4   324    324.            LDY  #PIA2          ;Base address of row 2 PIA
F99F 16    00A7     5   325    325.            LBRA METUPD         ;Go to metering update
                        326    326.     *
                        327    327.     *  Row 3 metering event (event sensor trigger)?
F9A2 B6    3001     5   328    328.     INT3   LDA  PIA3+1         ;Row 3 polled
F9A5 2A    1C       3   329    329.            BPL  INT4           ;If no interrupt, check row 4
F9A7 7D    D30F     7   330    330.            TST  DATA3+SENFLG   ;First interrupt since statistics update?
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ILC  Object       I  STMT   Line #   Source Statement                                              17:33:32  06-27-86

F9AA 26   2E      3  331     331.           BNE  INTGO4          ;No, initialize base addresses for metering update
F9AC 8E   D01D    6  332     332.           LDX  LKDAT3          ;Data block base address for malfunction test
F9AF 108E D029    7  333     333.           LDY  LKPIA3          ;PIA base address for malfunction test
F9B3 BD   FA3A    8  334     334.           JSR  MALTST          ;Check for potato sensor malfunction
F9B6 7C   D30F    7  335     335.           INC  DATA3+SENFLG    ;Set flag indicating malfunction test complete
F9B9 8E   D300    3  336     336.   INT3GO  LDX  #DATA3          ;Base address of row 3 data block
F9BC 108E 3000    4  337     337.           LDY  #PIA3           ;Base address of row 3 PIA
F9C0 16   0086    5  338     338.           LBRA METUPD          ;Go to metering update
                     339     339.   *
                     340     340.   *  Row 4 metering event (event sensor trigger)?
F9C3 B6   4001    5  341     341.   INT4    LDA  PIA4+1          ;Row 4 polled
F9C6 2A   1C      3  342     342.           BPL  INT5            ;If no interrupt, check row 5
F9C8 7D   D40F    7  343     343.           TST  DATA4+SENFLG    ;First interrupt since statistics update?
F9CB 26   0D      3  344     344.           BNE  INTGO4          ;No, initialize base addresses for metering update
F9CD 8E   D01F    6  345     345.           LDX  LKDAT4          ;Data block base address for malfunction test
F9D0 108E D02B    7  346     346.           LDY  LKPIA4          ;PIA base address for malfunction test
F9D4 BD   FA3A    8  347     347.           JSR  MALTST          ;Check for potato sensor malfunction
F9D7 7C   D40F    7  348     348.           INC  DATA4+SENFLG    ;Set flag indicating malfunction test complete
F9DA 8E   D400    3  349     349.   INTGO4  LDX  #DATA4          ;Base address of row 4 data block
F9DD 108E 4000    4  350     350.           LDY  #PIA4           ;Base address of row 4 PIA
F9E1 16   0065    5  351     351.           LBRA METUPD          ;Go to metering update
                     352     352.   *
                     353     353.   *  Row 5 metering event (event sensor trigger)?
F9E4 B6   5001    5  354     354.   INT5    LDA  PIA5+1          ;Row 5 polled
F9E7 2A   1C      3  355     355.           BPL  INT6            ;If no interrupt, check row 6
F9E9 7D   D50F    7  356     356.           TST  DATA5+SENFLG    ;First interrupt since statistics update?
F9EC 26   0D      3  357     357.           BNE  INTGO5          ;No, initialize base addresses for metering update
F9EE 8E   D021    6  358     358.           LDX  LKDAT5          ;Data block base address for malfunction test
F9F1 108E D02D    7  359     359.           LDY  LKPIA5          ;PIA base address for malfunction test
F9F5 BD   FA3A    8  360     360.           JSR  MALTST          ;Check for potato sensor malfunction
F9F8 7C   D50F    7  361     361.           INC  DATA5+SENFLG    ;Set flag indicating malfunction test complete
F9FB 8E   D500    3  362     362.   INTGO5  LDX  #DATA5          ;Base address of row 5 data block
F9FE 108E 5000    4  363     363.           LDY  #PIA5           ;Base address of row 5 PIA
FA02 16   0044    5  364     364.           LBRA METUPD          ;Go to metering update
                     365     365.   *
                     366     366.   *  Row 6 metering event (event sensor trigger)?
FA05 B6   6001    5  367     367.   INT6    LDA  PIA6+1          ;Row 6 polled
FA08 2A   1C      3  368     368.           BPL  POLCTD          ;If no interrupt, continue polling
FA0A 7D   D60F    7  369     369.           TST  DATA6+SENFLG    ;First interrupt since statistics update?
FA0D 26   0D      3  370     370.           BNE  INTGO6          ;No, initialize base addresses for metering update
FA0F 8E   D023    6  371     371.           LDX  LKDAT6          ;Data block base address for malfunction test
FA12 108E D02F    7  372     372.           LDY  LKPIA6          ;PIA base address for malfunction test
FA16 BD   FA3A    8  373     373.           JSR  MALTST          ;Check for potato sensor malfunction
FA19 7C   D60F    7  374     374.           INC  DATA6+SENFLG    ;Set flag indicating malfunction test complete
FA1C 8E   D600    3  375     375.   INTGO6  LDX  #DATA6          ;Base address of row 6 data block
FA1F 108E 6000    4  376     376.           LDY  #PIA6           ;Base address of row 6 PIA
FA23 16   0023    5  377     377.           LBRA METUPD          ;Go to metering update
                     378     378.   *
                     379     379.   *  Statistics update
FA26 B6   7001    5  380     380.   POLCTD  LDA  PIAS+1          ;Change row displayed request?
FA29 102A 0093    6  381     381.           LBPL UPDATE          ;No, proceed with statistics update?
                     382     382.   *
                     383     383.   *  Change row to be displayed
FA2D B6   7000    5  384     384.           LDA  PIAS            ;Dummy read to clear interrupt flag
FA30 7C   D013    7  385     385.           INC  AUTORW          ;Row autoincrement off
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ILC  Object         I  STMT  Line #  Source Statement

FA33 BD   FC6D      8  386    386.          JSR  DELTRW         ;Change rows displayed
FA36 16   01EB      5  387    387.          LBRA DISPLY         ;Refresh display for new row
FA39 3B            15  388    388.          RTI
                       389    389.   *
                       390    390.   *
                       391    391.   *  << Subroutine:MALTST - Check for potato sensor malfunction >>
                       392    392.   *
                       393    393.   *  I/O   X - Data block base address
                       394    394.   *         Y - PIA base address
                       395    395.   *
FA3A A6   03        5  396    396.   MALTST LDA  LEDDIS,X       ;Row display mask
FA3C E6   A4        4  397    397.          LDB  ,Y             ;Sensor input on B7
FA3E 2A   04        3  398    398.          BPL  LOW            ;Is sensor working?
FA40 84   BF        2  399    399.          ANDA #%10111111     ;No, alter display mask to indicate malfunction (B6)
FA42 20   02        3  400    400.          BRA  STORE2
FA44 8A   40        2  401    401.   LOW    ORA  #%01000000     ;Sensor works, display mask malfunction bit off
FA46 A7   03        5  402    402.   STORE2 STA  LEDDIS,X
FA48 39             5  403    403.          RTS
                       404    404.   *
                       405    405.   *
                       406    406.   *  << Routine:METUPD- Metering event update >>
                       407    407.   *
                       408    408.   *  I/O   X - Data block base address
                       409    409.   *         Y - PIA base address
                       410    410.   *
FA49 6C   84        6  411    411.   METUPD INC  ,X             ;Current events incremented
FA4B A6   A4        4  412    412.          LDA  ,Y             ;Data on A port (potato sensor on B7)
FA4D 2B   2A        3  413    413.          BMI  HIT            ;Successful metering event? Yes, continue at HIT
                       414    414.   *
                       415    415.   *  Unsuccessful metering event
FA4F 6C   01        7  416    416.   NOSEED INC  CNMISS,X       ;Current number of misses incremented
FA51 E6   02        5  417    417.          LDB  MISLED,X       ;Number of misses displayed on metering LEDs
FA53 C1   04        2  418    418.          CMPB #04            ;Have four consecutive misses occured?
FA55 27   03        3  419    419.          BEQ  ELTST          ;Yes, increment number of consecutive misses
FA57 5C             2  420    420.          INCB                ;Number of consecutive misses incremented
FA58 E7   02        5  421    421.          STB  MISLED,X       ;Number of consecutive misses stored
                       422    422.   *
                       423    423.   *  Defective element test
FA5A A6   04        5  424    424.   ELTST  LDA  NEXTEL,X       ;Pointer to no. of consecutive misses for this element
FA5C E6   86        5  425    425.          LDB  A,X            ;Number of consecutive misses for current element
FA5E C1   04        2  426    426.          CMPB #04            ;Four consecutive misses on this element?
FA60 27   08        3  427    427.          BEQ  BUZZ           :  Yes, buzzer flag set
FA62 7F   D039      7  428    428.          CLR  BUZFLG         ;Buzzer flag reset (off)
FA65 5C             2  429    429.          INC  B              ;Increment no. of consecutive misses for this element
FA66 E7   86        5  430    430.          STB  A,X            ;Number of consecutive misses stored
FA68 20   03        3  431    431.          BRA  UPMISS
FA6A 7C   D039      7  432    432.   BUZZ   INC  BUZFLG         ;Buzzer flag set (off)
                       433    433.   *
                       434    434.   * Number of consecutive misses incremented and checked for overflow (64 max.)
FA6D A6   88 10     5  435    435.   UPMISS LDA  CONMIS,X
FA70 4C             2  436    436.          INCA                ;Increment number of consecutive misses
FA71 A7   88 10     5  437    437.          STA  CONMIS,X
FA74 48             2  438    438.          ASLA
FA75 2B   16        3  439    439.          BMI  CLRMIS         ;If 64 consecutive misses have occured, record & reset
FA77 20   23        3  440    440.          BRA  METCON
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ILC  Object      I  STMT  Line #  Source Statement                                                       17:33:32  06-27-86

                    441    441.   *
                    442    442.   *  Successful metering event
FA79 E6   02     5  443    443.   HIT    LDB  MISLED,X       ;Current number of consecutive misses displayed
FA7B 27   03     3  444    444.          BEQ  CLRELM         ;Is number of misses displayed = 0? If yes goto CLRCON
FA7D 5A          2  445    445.          DECB                ;Decrease consecutive miss count (top illuminated
FA7E E7   02     5  446    446.          STB  MISLED,X       ;  yellow LED turned off)
FA80 A6   04     5  447    447.   CLRELM LDA  NEXTEL,X       ;Offset to current element's consecutive miss count
FA82 6F   86     7  448    448.          CLR  A,X            ;Clear consecutive miss count for current element
FA84 A6   88 10  5  449    449.          LDA  CONMIS,X       ;Number of consecutive misses
FA87 27   13     3  450    450.          BEQ  METCON         ;Was previous event a miss?
FA89 7F   D039   7  451    451.          CLR  BUZFLG         ;Defective element indicators off
FA8C 48          2  452    452.          ASLA                ;Yes, record consecutive number of misses
FA8D 8B   7F     2  453    453.   CLRMIS ADDA #127           ;2 byte adjust and then offset is added
FA8F E6   86     5  454    454.          LDB  A,X
FA91 5C          2  455    455.          INCB                ;Respective consecutive of misses is incremented
FA92 E7   86     5  456    456.          STB  A,X
FA94 24   06     3  457    457.          BCC  METCON         ;Carry from addition?
FA96 4A          2  458    458.          DECA                ;Yes
FA97 6C   86     7  459    459.          INC  A,X            ;Increment MSB of consecutive miss counter
FA99 6F   88 10  7  460    460.          CLR  CONMIS,X       ;Consecutive number of miss count is cleared
                    461    461.   *
                    462    462.   *  Update pointer to next element checked for 4 consecutive misses
FA9C E6   04     5  463    463.   METCON LDB  NEXTEL,X       ;Pointer to current element in this row
FA9E 5A          2  464    464.          DECB                ;Pointer to next element to be monitored in this row
FA9F C1   11     2  465    465.          CMPB #$11           ;Has the metering chain made a complete revolution?
FAA1 26   03     3  466    466.          BNE  DISLED         ;No, store pointer
FAA3 F6   D005   5  467    467.          LDB  ELOFFS         ;Yes, reset pointer for 1st element in row
FAA6 E7   04     5  468    468.   DISLED STB  NEXTEL,X       ;Store pointer
                    469    469.   *
                    470    470.   *  LEDs are refreshed
FAA8 36   20     5  471    471.          PSHU Y              ;PIA base address stacked
FAAA 108E FDBB   4  472    472.          LDY  #TABLE         ;Table for consecutive no. of missess to LED format
FAAE A6   02     5  473    473.          LDA  MISLED,X       ;Number of misses displayed
FAB0 E6   A6     5  474    474.          LDB  A,Y            ;New metering display mask
FAB2 E4   03     5  475    475.          ANDB LEDDIS,X       ;Combine status LED mask with metering LED mask
FAB4 7D   D039   7  476    476.          TST  BUZFLG         ;Malfunctioning element?
FAB7 27   02     3  477    477.          BEQ  ONGO
FAB9 C4   2F     2  478    478.          ANDB #%00101111     ;Yes, sensor malfunction LEDs and buzzer on
FABB 37   20     5  479    479.   ONGO   PULU Y              ;Retrieve PIAs base address
FABD E7   22     5  480    480.          STB  2,Y            ;Display mask sent to LEDs
FABF 3B         15  481    481.          RTI
                    482    482.   *
                    483    483.   *
                    484    484.   *  << Routine:UPDATE - Statistics update for each data block (every 5 sec) >>
                    485    485.   *
                    486    486.   *  Check mode 1 row autoincrement toggel
FAC0 F6   7000   5  487    487.   UPDATE LDB  PIA5           ;Row autoincrement toggel on B6 of microswitch PIA
FAC3 C5   40     2  488    488.          BITB #%01000000     ;Mode 1 (%Miss) row autoincrement?
FAC5 27   05     3  489    489.          BEQ  RINC           ;Yes
FAC7 7F   D013   7  490    490.          CLR  AUTORW         ;No reset row autoincrement flag
FACA 20   05     3  491    491.          BRA  UPSTRT
FACC C6   01     2  492    492.   RINC   LDB  #$01           ;Row autoincrement, set flag
FACE F7   D013   5  493    493.          STB  AUTORW
                    494    494.   *
FAD1 F6   D004   5  495    495.   UPSTRT LDB  NOROWS         ;Number of rows
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ILC  Object       I  STMT   Line #    Source Statement

FAD4 8E    1000   3   496     496.           LDX  #PIA1          ;Base address of row 1 PIA
FAD7 108E  D100   4   497     497.           LDY  #DATA1         ;Base address of row 1 data block
FADB BD    FAF0   8   498     498.    UPDCTD JSR  CALC           ;Statistics calculations
FADE 6F    2F     7   499     499.           CLR  SENFLG,Y       ;Sensor malfunction check flag reset
FAE0 5A           2   500     500.           DECB
FAE1 27    0A     3   501     501.           BEQ  FINISH         ;All rows updated? If so, refresh display
FAE3 30    89 1000 8  502     502.           LEAX $1000,X        ;Base address of next row PIA in X
FAE7 31    A9 0100 8  503     503.           LEAY $0100,Y        ;Base address for next row's data base
FAEB 20    EE     3   504     504.           BRA  UPDCTD         ;Update next row
FAED 16    0134   5   505     505.    FINISH LBRA DISPLY         ;LCD display refresh
                      506     506.    *
                      507     507.    *
                      508     508.    *  << Subroutine:CALC - Calculations for statistics update & event sensor test >>
                      509     509.    *
                      510     510.    *  I/O  B - Data block number to be updated
                      511     511.    *       X - PIA base address
                      512     512.    *       Y - Data block base address
                      513     513.    *
                      514     514.    *  1. Planting rate (metering events/min)
                      515     515.    *
FAF0 36    14     6   516     516.    CALC   PSHU B,X            ;Stack
FAF2 A6    A4     4   517     517.           LDA  ,Y             ;Current number of events
FAF4 C6    0C     2   518     518.           LDB  #12            ;interrupts occur at 5 sec intervals, therefore
FAF6 3D          11   519     519.           MUL                 ;  multiplying by 12 gives events/min
FAF7 ED    20     6   520     520.           STD  PLRATE,Y       ;Store in planting rate memory location
                      521     521.    *
                      522     522.    *  2. Current percent misses
                      523     523.    *
FAF9 36    10     5   524     524.           PSHU X              ;Stack PIA address corresponding to data block
FAFB E6    A4     4   525     525.           LDB ,Y              ;Current number of events
FAFD 8E    D002   3   526     526.           LDX #DIVWS+2
FB00 E7    84     4   527     527.           STB ,X              ;Divisor placed in division workspace
FB02 8E    D000   3   528     528.           LDX #DIVWS          ;Base address of divison workspace
FB05 86    64     2   529     529.           LDA #100
FB07 E6    21     5   530     530.           LDB 1,Y             ;Number of misses
FB09 3D          11   531     531.           MUL                 ;Multiplied by 100
FB0A ED    84     5   532     532.           STD ,X              ;Dividend placed in division workspace
FB0C BD    FB50   8   533     533.           JSR DIVISN          ;Divide
FB0F 5D           2   534     534.           TSTB                ;Quotient = 0?
FB10 2A    01     3   535     535.           BPL ENDDIV          ;No
FB12 5F           2   536     536.           CLRB                ;Divison by 0 % misses, quotient set to 0
FB13 4F           2   537     537.    ENDDIV CLRA
FB14 ED    28     6   538     538.           STD  PERMIS,Y       ;Store % misses
FB16 37    10     5   539     539.           PULU X              ;PIA base address restored
                      540     540.    *
                      541     541.    *  3. Update total number of events and check for malfunctioning element sensor
                      542     542.
FB18 A6    A4     4   543     543.           LDA  ,Y             ;Current number of events (number added)
FB1A 26    06     3   544     544.           BNE  EVGO           ;Has an event occurred in last 5 sec?
FB1C C6    EF     2   545     545.           LDB  #%11101111     ;No, event sensor malfunction mask set to on
FB1E E4    23     5   546     546.           ANDB LEDDIS,Y       ;LED display mask updated
FB20 20    04     3   547     547.           BRA  STORE
FB22 C6    10     2   548     548.    EVGO   LDB  #%00010000     ;Sensor functioning, malfunction mask reset to off
FB24 EA    23     5   549     549.           ORB  LEDDIS,Y       ;LED display mask updated
FB26 E7    23     5   550     550.    STORE  STB  LEDDIS,Y       ;LED display mask stored
```

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ILC  Object     I  STMT   Line #    Source Statement

FB28 E4   02    5   551    551.            ANDB 2,X          ;Mask combined with display LEDs
FB2A E7   02    5   552    552.            STB  2,X          ;LED display is refreshed
FB2C 30   27    5   553    553.            LEAX TEVENT,Y     ;Address of total number of events (number added to)
FB2E BD   FB47  8   554    554.            JSR  ADD          ;Add current events to total events
FB31 6F   A4    6   555    555.            CLR  ,Y           ;Zero number of current events
                    556    556.   *
                    557    557.   *  4. Update total number of misses
                    558    558.   *
FB33 30   25    5   559    559.            LEAX TMIS,Y       ;Address of total number of misses (number to add to)
FB35 A6   21    5   560    560.            LDA  CNMISS,Y     ;Current number of misses
FB37 BD   FB47  8   561    561.            JSR  ADD          ;Add current misses to total misses
FB3A 6F   21    7   562    562.            CLR  CNMISS,Y     ;Zero current misses
                    563    563.   *
                    564    564.   *  5. Update total number of successful metering events (plants)
                    565    565.   *
FB3C 30   25    5   566    566.            LEAX TMIS,Y       ;Address of total number of misses (number to subtract)
FB3E EC   27    6   567    567.            LDD  TEVENT,Y     ;Total number of events (number to subtract from)
FB40 A3   84    6   568    568.            SUBD ,X           ;Subtract
FB42 ED   29    6   569    569.            STD  THITS,Y      ;Store result
FB44 37   14    6   570    570.            PULU B,X          ;Restore current data block number (row)
FB46 39         5   571    571.            RTS               ;End of update calculations for this data block
                    572    572.   *
                    573    573.   *
                    574    574.   *  << Subroutine:ADD - Addition of 1 byte number to a 2 byte number >>
                    575    575.   *
                    576    576.   *  I/P  A - Number to add
                    577    577.   *       X - Address of number to add to
                    578    578.   *
                    579    579.   *  O/P  X - 2 byte addition result
                    580    580.   *
FB47 AB   01    5   581    581.   ADD      ADDA 1,X          ;LSB added
FB49 A7   01    5   582    582.            STA  1,X          ;LSB store
FB4B 24   02    3   583    583.            BCC  OUT          ;Result < 128, no carry
FB4D 6C   84    6   584    584.            INC  ,X           ;Add 1 to MSB
FB4F 39         5   585    585.   OUT      RTS
                    586    586.   *
                    587    587.   *
                    588    588.   *  << Subroutine:DIVISN - Division >>
                    589    589.   *
                    590    590.   *  I/P  X - Base address of division work space
                    591    591.   *
                    592    592.   *  O/P  A - Remainder
                    593    593.   *       B - Quotient
                    594    594.   *
FB50 86   08    2   595    595.   DIVISN LDA  #08            ;Count=8
FB52 B7   D003  5   596    596.          STA  CNTR1
FB55 EC   84    5   597    597.          LDD  ,X             ;Get dividend
FB57 58         2   598    598.   DIVIDE ASLB                ;Shift dividend, Quotient
FB58 49         2   599    599.          ROLA
FB59 A1   02    5   600    600.          CMPA 2,X            ;Trial subtraction successful?
FB5B 25   03    3   601    601.          BCS  CHKCNT         ;No
FB5D A0   02    5   602    602.          SUBA 2,X            ;Yes, subtract and set bit in quotient
FB5F 5C         2   603    603.          INCB
FB60 7A   D003  7   604    604.   CHKCNT DEC  CNTR1
FB63 26   F2    3   605    605.          BNE  DIVIDE
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ILC  Object        I  STMT   Line #   Source Statement                                                17:33:32  06-27-86
FB65 39            5  606    606.            RTS
                      607    607.     *
                      608    608.     *
                      609    609.     *
FC00                  610    610.            ORG NMI
                      611    611.     *
                      612    612.     * <<<< NMI service routine - Change modes and refreshes display >>>>
                      613    613.     *
                      614    614.     *  << Routine:CMODE - Change modes >>
                      615    615.     *
FC00 B6    D008    5  616    616.     CMODE  LDA  MODE            ;Current mode
FC03 4C            2  617    617.            INCA                 ;Next mode
FC04 81    05      2  618    618.            CMPA #05             ;Reseed to mode 0?
FC06 26    04      3  619    619.            BNE  HERE            ;No
FC08 4F            2  620    620.            CLRA                 ;Yes
FC09 7C    D013    7  621    621.            INC  AUTORW          ;Set row autoincrement flag (no mode change)
FC0C B7    D008    5  622    622.     HERE   STA  MODE
FC0F 8E    FD86    3  623    623.            LDX  #MODOFF         ;Base address of data block offset for display value
FC12 E6    86      5  624    624.            LDB  A,X             ;Data block offset for display value
FC14 F7    D016    5  625    625.            STB  OFFSET
FC17 48            2  626    626.            ASLA                 ;Mode X 2
FC18 108E  FD70    4  627    627.            LDY  #LCDMES         ;Base address for mode labels
FC1C AE    A6      6  628    628.            LDX  A,Y             ;Address of mode label
FC1E BF    D014    6  629    629.            STX  DISLAB
FC21 7C    D03A    7  630    630.            INC  MODFLG          ;Display update indicated
                      631    631.     *
                      632    632.     *  << Routine:DISPLY - Refresh display >>
                      633    633.     *
FC24 7D    D008    7  634    634.     DISPLY TST  MODE
FC27 26    08      3  635    635.            BNE  DISCTD          ;Mode 0 (%Misses)?
FC29 7D    D013    7  636    636.            TST  AUTORW          ;Yes
FC2C 26    03      3  637    637.            BNE  DISCTD          ;Row autoincrement?
FC2E BD    FC6D    8  638    638.            JSR  DELTRW          ;Yes, change rows
                      639    639.     *
FC31 7D    D03A    7  640    640.     DISCTD TST  MODFLG
FC34 27    0A      3  641    641.            BEQ  VALDMP
FC36 BE    D014    6  642    642.            LDX  DISLAB          ;Address of mode label
FC39 C6    0A      2  643    643.            LDB  #10             ;Number of characters in mode label
FC3B BD    FD65    8  644    644.            JSR  DUMP            ;Mode label dumped to LCD display
FC3E 20    04      3  645    645.            BRA  VDCTD
FC40 86    0A      2  646    646.     VALDMP LDA  #%00001010
FC42 97    00      4  647    647.            STA  LCD
FC44 BE    D010    6  648    648.     VDCTD  LDX  DISROW          ;Data block base address
FC47 F6    D016    5  649    649.            LDB  OFFSET          ;Offset from data block base
FC4A EC    85      6  650    650.            LDD  B,X             ;Value to be displaed
FC4C 10B3  D006    8  651    651.            CMPD LASVAL          ;Has value to be displayed changed from last display
FC50 27    0E      3  652    652.            BEQ  TIMOUT          ;No, service timers
FC52 FD    D006    6  653    653.            STD  LASVAL          ;Displayed value is stored
FC55 BD    FCB1    8  654    654.            JSR  HEXCON          ;Convert value to be displayed to ASCII
FC58 8E    D031    3  655    655.            LDX  #VALUE          ;Base address of ASCII display value
FC5B C6    06      2  656    656.            LDB  #06             ;Number of characters in value label
FC5D BD    FD65    8  657    657.            JSR  DUMP            ;Value dumped to display
                      658    658.     *
                      659    659.     *  Display & calculate timers are serviced for 5 sec count down
FC60 B6    8001    5  660    660.     TIMOUT LDA  PTM1+1          ;Clear interrupt flag
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ILC  Object        I  STMT   Line #    Source Statement                                      17:33:32  06-27-86

FC63 BE   8007     6   661    661.            LDX  LATCH3         ;Reload timer 3
FC66 8E   0032     3   662    662.            LDX  #50
FC69 BF   8006     6   663    663.            STX  COUNT3
FC6C 3B           15   664    664.            RTI
                       665    665.     *
                       666    666.     *
                       667    667.     *  << Subroutine:DELTRW - Next row displayed >>
                       668    668.     *
FC6D BE   D010     6   669    669.     DELTRW LDX  DISROW         ;Base address of data block currently displayed
FC70 A6   03       5   670    670.            LDA  LEDDIS,X
FC72 8A   20       2   671    671.            ORA  #%00100000
FC74 A7   03       5   672    672.            STA  LEDDIS,X       ;Row select LED of current row off
FC76 86   20       2   673    673.            LDA  #%00100000
FC78 108E D017     7   674    674.            LDY  CURPIA
FC7C AA   22       5   675    675.            ORA  2,Y
FC7E A7   22       5   676    676.            STA  2,Y            ;Row display LED turned off
FC80 B6   D012     5   677    677.            LDA  CURROW
FC83 4C            2   678    678.            INCA                ;Row number currently displayed is incremented
FC84 B1   D004     5   679    679.            CMPA NOROWS         ;Initialize to row 1?
FC87 23   08       3   680    680.            BLS  NOBACK
FC89 8E   D100     3   681    681.            LDX  #DATA1         ;Yes, reinitialize data block and PIA addresses
FC8C 108E 1000     4   682    682.            LDY  #PIA1
FC90 86   01       2   683    683.            LDA  #01
FC92 20   08       3   684    684.            BRA  STOROW
FC94 30   89 0100  8   685    685.     NOBACK LEAX $0100,X        ;Increment data block and PIA addresses
FC98 31   A9 1000  8   686    686.            LEAY $1000,Y
FC9C BF   D010     6   687    687.     STOROW STX  DISROW         ;Update display status variables
FC9F 10BF D017     7   688    688.            STY  CURPIA
FCA3 B7   D012     5   689    689.            STA  CURROW
FCA6 C6   DF       2   690    690.            LDB  #%11011111     ;Row select LED masked to on
FCA8 E4   03       5   691    691.            ANDB LEDDIS,X
FCAA E7   03       5   692    692.            STB  LEDDIS,X       ;LED display mask updated
FCAC E4   22       5   693    693.            ANDB 2,Y
FCAE E7   22       5   694    694.            STB  2,Y            ;Row select LED turned on
FCB0 39            5   695    695.            RTS
                       696    696.     *
                       697    697.     *
                       698    698.     *  << Subroutine:HEXCON - Select and convert value for LCD display >>
                       699    699.     *
                       700    700.     *
                       701    701.     *  Convert hexidecimal representation of number to decimal counters
FCB1 1083 2710     5   702    702.     HEXCON CMPD #10000         ;Compare value to 10,000
FCB5 25   08       3   703    703.            BLO  NEXT2          ;If less, no digit in ten thousands
FCB7 83   2710     4   704    704.            SUBD #10000         ;Subtract 10,000
FCBA 7C   D009     7   705    705.            INC  CNTR           ;10,000 counter is incremented
FCBD 20   F2       3   706    706.            BRA  HEXCON         ;Try again
FCBF 1083 03E8     5   707    707.     NEXT2  CMPD #1000          ;Compare value to 1,000
FCC3 25   08       3   708    708.            BLO  NEXT3          ;If less, no digit in thousands
FCC5 83   03E8     4   709    709.            SUBD #1000          ;Subtract 1,000
FCC8 7C   D00A     7   710    710.            INC  CNTR+1         ;1,000 counter is incremented
FCCB 20   F2       3   711    711.            BRA  NEXT2          ;Try again
FCCD 1083 0064     5   712    712.     NEXT3  CMPD #100           ;Compare value to 100
FCD1 25   08       3   713    713.            BLO  NEXT4          ;If less, no digit in hundreds
FCD3 83   0064     4   714    714.            SUBD #100           ;Subtract 1000
FCD6 7C   D00B     7   715    715.            INC  CNTR+2         ;100 counter is incremented
```

```
ILC  Object      I  STMT   Line #   Source Statement

FCD9 20   F2     3   716    716.          BRA  NEXT3         ;Try again
FCDB 1083 000A   5   717    717.   NEXT4  CMPD #10           ;Compare value to 10
FCDF 25   08     3   718    718.          BLO  NEXT5         ;If less, no digit in tens
FCE1 83   000A   4   719    719.          SUBD #10           ;Subtract 10
FCE4 7C   D00C   7   720    720.          INC  CNTR+3        ;10 counter is incremented
FCE7 20   F2     3   721    721.          BRA  NEXT4         ;Try again
FCE9 F7   D00D   5   722    722.   NEXT5  STB  CNTR+4        ;Remainder stored in 1 counter
                     723    723.   *
                     724    724.   *  Conversion of decimal numbers to ASCII format stored starting at memory
                     725    725.   *     location VALUE
FCEC 7F   D00F   7   726    726.          CLR  ZFLG          ;Flag used to delete leading zeros
FCEF 86   20     2   727    727.          LDA  #$20          ;ASCII blank
FCF1 B7   D031   5   728    728.          STA  VALUE         ;Space between labels and numbers
FCF4 86   30     2   729    729.          LDA  #%00110000    ;Base for ASCII conversion
FCF6 1F   89     7   730    730.          TFR  A,B
FCF8 FB   D009   5   731    731.          ADDB CNTR          ;First digit
FCFB BD   FD3D   8   732    732.          JSR  LDZERO        ;Check for leading zeros
FCFE F7   D032   5   733    733.          STB  VALUE+1
FD01 1F   89     7   734    734.          TFR  A,B
FD03 FB   D00A   5   735    735.          ADDB CNTR+1        ;Second digit
FD06 BD   FD3D   8   736    736.          JSR  LDZERO        ;Check for leading zeros
FD08 F7   D033   5   737    737.          STB  VALUE+2
FD0C 1F   89     7   738    738.          TFR  A,B
FD0E FB   D00B   5   739    739.          ADDB CNTR+2        ;Third digit
FD11 BD   FD3D   8   740    740.          JSR  LDZERO        ;Check for leading zeros
FD14 F7   D034   5   741    741.          STB  VALUE+3
FD17 1F   89     7   742    742.          TFR  A,B
FD19 FB   D00C   5   743    743.          ADDB CNTR+3        ;Fourth digit
FD1C BD   FD3D   8   744    744.          JSR  LDZERO        ;Check for leading zeros
FD1F 7C   D00F   7   745    745.          INC  ZFLG          ;No more blanks allowed
FD22 F7   D035   5   746    746.          STB  VALUE+4
FD25 1F   89     7   747    747.          TFR  A,B
FD27 FB   D00D   5   748    748.          ADDB CNTR+4        ;Fifth digit
FD2A F7   D036   5   749    749.          STB  VALUE+5
FD2D 7F   D009   7   750    750.          CLR  CNTR          ;Clears counters for next conversion
FD30 7F   D00A   7   751    751.          CLR  CNTR+1
FD33 7F   D00B   7   752    752.          CLR  CNTR+2
FD36 7F   D00C   7   753    753.          CLR  CNTR+3
FD39 7F   D00D   7   754    754.          CLR  CNTR+4
FD3C 39          5   755    755.          RTS
                     756    756.   *
                     757    757.   *
                     758    758.   *  << Subroutine:LDZERO - Check for leading zeros on display >>
                     759    759.   *
FD3D 7D   D00F   7   760    760.   LDZERO TST  ZFLG          ;Was there a previous non zero number
FD40 26   08     3   761    761.          BNE  YESEND        ;If there was return
FD42 C1   30     2   762    762.          CMPB #$30          ;Is this charactre a zero?
FD44 26   04     3   763    763.          BNE  NOTEND        ;No
FD46 C6   20     2   764    764.          LDB  #$20          ;ASCII blank
FD48 20   03     3   765    765.          BRA  YESEND
FD4A 7C   D00F   7   766    766.   NOTEND INC  ZFLG          ;Set flag for non-zero number
FD4D 39          5   767    767.   YESEND RTS
                     768    768.   *  << Subroutine:CLRLCD - Clear LCD display >>
                     769    769.   *
FD4E 86   8A     2   770    770.   CLRLCD LDA  #%10001010    ;Clear LCD flag
```

```
ILC  Object          I  STMT  Line #   Source Statement

FD50 97    00        4   771    771.          STA  LCD           ;Send to LCD
FD52 4F              2   772    772.          CLRA
FD53 97    00        4   773    773.          STA  LCD
FD55 BD    FD59      8   774    774.          JSR  DELAY         ;Delay character latched to LCD display
FD58 39              5   775    775.          RTS
                         776    776.    *
                         777    777.    *
                         778    778.    *  << Subroutine:DELAY - 0.786 milli sec delay for LCD to latch character >>
                         779    779.    *
                         780    780.    *  I/P  X - Address of character sent to display
FD59 36    10        5   781    781.    DELAY  PSHU X            ;Stack
FD5B 8E    015E      3   782    782.           LDX  #350         ;Initial count down value
FD5E 30    1F        5   783    783.    WAIT   LEAX -1,X         ;Count down
FD60 26    FC        3   784    784.           BNE  WAIT         ;Delay complete? If not, continue count down
FD62 37    10        5   785    785.           PULU X            ;Restore
FD64 39              5   786    786.           RTS
                         787    787.    *
                         788    788.    *
                         789    789.    *  << Subroutine:DUMP - Contents of memory locations dumped to LCD display >>
                         790    790.    *
                         791    791.    *  I/P  B - Number of memory locations to dump
                         792    792.    *       X - Address of first memory location to dump
                         793    793.    *
FD65 A6    80        6   794    794.    DUMP   LDA  ,X+          ;Load character to dump
FD67 97    00        4   795    795.           STA  LCD          ;Send to display
FD69 BD    FD59      8   796    796.           JSR  DELAY        ;Allow time for LCD latch
FD6C 5A              2   797    797.           DECB
FD6D 26    F6        3   798    798.           BNE  DUMP         ;Last character? If not, continue dump
FD6F 39              5   799    799.           RTS
                         800    800.    *
                         801    801.    *
                         802    802.    *
                         803    803.    *  <<< ROM Data >>>
                         804    804.    *
                         805    805.    *  < Addresses of mode labels >
                         806    806.    *
FD70 FDA0FDAAFDB4        807    807.    LCDMES FDB PMISAS,NEVAS,NMISAS,PLANTS,PMAS
FD76 FDBEFDC8
                         808    808.    *
                         809    809.    *  < Data block pointers to for malfunctioning potato sensor check >
                         810    810.    *
FD7A D200D300D400        811    811.    CKDAT  FDB DATA2,DATA3,DATA4
                         812    812.    *
                         813    813.    *  < PIA pointers for malfunctioning potato sensor check >
                         814    814.    *
FD80 200030004000        815    815.    CKPIA  FDB PIA2,PIA3,PIA4
                         816    816.    *
                         817    817.    *  < Table - Offsets from data blocks base of number to display >
                         818    818.    *
FD86 0B07050900          819    819.    MODOFF FCB $0B,$07,$05,$09,$0D
                         820    820.    *
                         821    821.    *  < Table - Number of consecutive misses metering mask >
                         822    822.    *
FD8B FFFEFCF8F0          823    823.    TABLE  FCB %11111111,%11111110,%11111100,%11111000,%11110000
                         824    824.    *
```

```
ILC  Object         I  STMT   Line #   Source Statement

                       825     825.    *  < Display messages and mode labels >
                       826     826.    *
FD90 3D504F544154      827     827.    HELFLG FCC '=POTATO=MONITOR='
FD96 4F3D4D4F4E49
FD9C 544F523D
FDA0 25204D495353      828     828.    PMISAS FCC '% MISSES  '
FDA6 45532020
FDAA 4E4F2E204556      829     829.    NEVAS  FCC 'NO. EVENTS'
FDB0 454E5453
FDB4 4E4F2E204D49      830     830.    NMISAS FCC 'NO. MISSES'
FDBA 53534553
FDBE 4E4F2E20504C      831     831.    PLANTS FCC 'NO. PLANTS'
FDC4 414E5453
FDC8 504F5441544F      832     832.    PMAS   FCC 'POTATO/MIN'
FDCE 2F4D494E
                       833     833.    *
                       834     834.    *  < Flags for LCD initialization >
                       835     835.    *
FDD2 686B616D6265      836     836.    FLAGS  FCB $68,$6B,$61,$6D,$62,$65,$67,$6E,$00,$8A
FDD8 676E008A
                       837     837.    *
                       838     838.    *
                       839     839.    *  <<<< System vectors assigned >>>>
                       840     840.    *
FFF0                   841     841.           ORG $FFF0
FFF0 000000000000      842     842.           FDB 0,0,0,0,IRQ,0,NMI,RESET
FFF6 0000F9600000
FFFC FC00F800
0000                   843     843.           END
```

```
PPM  ;(Potato pllanter monitor)                    CROSS-REFERENCE                                   Page   17

SYMBOL    VALUE  DEFN  REFERENCES                                                               17:33:32  06-27-86

ADD       FB47   581   554   561
AUTORW    D013    48   167   385   490   493   621   636
BUZFLG    D039    65   428   432   451   476
BUZZ      FA6A   432   427
CALC      FAF0   516   498
CHKCNT    FB60   604   601
CKDAT     FD7A   811   198
CKPIA     FD80   815   217
CLRELM    FA80   447   444
CLRLCD    FD4E   770   109
CLRMIS    FA8D   453   439
CMODE     FC00   616
CNEV      0000    78
CNMISS    0001    79   416   560   562
CNTR      D009    44   705   710   715   720   722   731   735   739   743   748   750   751   752   753   754
CNTR1     D003    39   596   604
CONMIS    0010    89   435   437   449   460
COUNT1    8002    29   245
COUNT2    8004    30   241
COUNT3    8006    31   243   663
CURPIA    D017    51   162   674   688
CURROW    D012    47   168   677   689
DATA1     D100    67   159   172   189   304   309   310   497   681
DATA2     D200    68   174   317   322   323   811
DATA3     D300    69   175   330   335   336   811
DATA4     D400    70   176   343   348   349   811
DATA5     D500    71   177   356   361   362
DATA6     D600    72   178   369   374   375
DELAY     FD59   781   103   774   796
DELTRW    FC6D   669   386   638
DISCTD    FC31   640   635   637
DISLAB    D014    49   164   629   642
DISLED    FAA6   468   466
DISPLY    FC24   634   387   505
DISROW    D010    46   160   648   669   687
DIVIDE    FB57   598   605
DIVISN    FB50   595   533
DIVWS     D000    38   526   528
DUMP      FD65   794   114   644   657   798
ELOFFS    D005    41   188   467
ELTST     FA5A   424   419
ENDDIV    FB13   537   535
EVGO      FB22   548   544
FINISH    FAED   505   501
FLAGS     FDD2   836   104
FLGDSP    F80D   105   108
HELFLG    FD90   827   112
HERE      FC0C   622   619
HEXCON    FCB1   702   654   706
HIT       FA79   443   413
INCDAT    F8E0   214   211
INCPIA    F908   232   229
INTGO1    F977   310   305
INTGO2    F998   323   318
INTGO4    F9DA   349   331   344
```

```
PPM  ;(Potato pilanter monitor)                         CROSS-REFERENCE                                       Page   18

                                                                                                     17:33:32  06-27-86
SYMBOL    VALUE  DEFN  REFERENCES

INTG05    F9FB   362   357
INTG06    FA1C   375   370
INT1      F960   302
INT2      F981   315   303
INT3      F9A2   328   316
INT3GO    F9B9   336
INT4      F9C3   341   329
INT5      F9E4   354   342
INT6      FA05   367   355
IRQ       F960    14   298   842
LASVAL    D006    42   165   651   653
LATCH1    8003    32
LATCH2    8005    33
LATCH3    8007    34   661
LCD       0000    19   106   647   771   773   795
LCDINT    F807   103
LCDMES    FD70   807   627
LDZERO    FD3D   760   732   736   740   744
LEDDIS    0003    81   172   174   175   176   177   178   396   402   475   546   549   550   670   672   691   692
LKDAT     F8CF   206   215
LKDAT1    D019    52   205   306
LKDAT2    D01B    53   319
LKDAT3    D01D    54   332
LKDAT4    D01F    55   345
LKDAT5    D021    56   358
LKDAT6    D023    57   371
LKPIA     F8FA   225   233
LKPIA1    D025    58   224   307
LKPIA2    D027    59   320
LKPIA3    D029    60   333
LKPIA4    D02B    61   346
LKPIA5    D02D    62   359
LKPIA6    D02F    63   372
LOOP      F948   289   290
LOW       FA44   401   398
MALTST    FA3A   396   308   321   334   347   360   373
MEMINT    F85D   153
METCON    FA9C   463   440   450   457
METUPD    FA49   411   312   325   338   351   364   377
MISLED    0002    80   417   421   443   446   473
MODE      D008    43   616   622   634
MODFLG    D03A    66   630   640
MODOFF    FD86   819   623
NCLR1     F860   154   156
NEVAS     FDAA   829   807
NEXOFF    F93F   285   288
NEXTEL    0004    82   190   424   447   463   468
NEXT2     FCBF   707   703   711
NEXT3     FCCD   712   708   716
NEXT4     FCDB   717   713   721
NEXT5     FCE9   722   718
NMI       FC00    15   610   842
NMISAS    FDB4   830   807
NOBACK    FC94   685   680
NOROWS    D004    40   185   199   210   213   218   231   281   495   679
```

```
PPM  ;(Potato pilanter monitor)                        CROSS-REFERENCE                                  Page   19

SYMBOL   VALUE  DEFN  REFERENCES                                                                 17:33:32  06-27-86

NOSEED    FA4F   416
NOTEND    FD4A   766   763
OFFINT    FBB2   190   193
OFFSET    D016    50   170   625   649
ONGO      FABB   479   477
OUT       FB4F   585   583
PERMIS    0008    86   169   538
PIAINT    F820   119
PIARES    F83F   133   147
PIAS      7000    26   120   121   122   123   125   127   131   183   186   380   384   487
PIA1      1000    20   130   161   302   311   496   682
PIA2      2000    21   315   324   815
PIA3      3000    22   328   337   815
PIA4      4000    23   341   350   815
PIA5      5000    24   354   363
PIA6      6000    25   367   376
PLANTS    FDBE   831   807
PLRATE    000D    87   520
PMAS      FDC8   832   807
PMISAS    FDA0   828   163   807
POLCTD    FA26   380   368
PTM1      8000    28   250   258   266   278   660
RESET     F800    13    97   842
RINC      FACC   492   489
SENFLG    000F    88   304   309   317   322   330   335   343   348   356   361   369   374   499
SETPIA    F8E6   217   208
SETPTM    F90E   240   227
SSTACK    D800    74    98
STKINT    F800    98
STORE     FB26   550   547
STORE2    FA46   402   400
STOROW    FC9C   687   684
TABLE     FD8B   823   472
TEVENT    0007    84   553   567
THITS     0009    85   569
TIMOUT    FC60   660   652
TMIS      0005    83   559   566
UPDATE    FAC0   487   381
UPDCTD    FADB   498   504
UPMISS    FA6D   435   431
UPSTRT    FAD1   495   491
USTACK    D740    73    99
VALDMP    FC40   646   641
VALUE     D031    64   655   728   733   737   741   746   749
VDCTD     FC44   648   645
WAIT      FD5E   783   784
YESEND    FD4D   767   761   765
ZFLG      D00F    45   726   745   760   766
```

13. APPENDIX F. MONITOR MEMORY MAPS

F1. Monitor System Memory Map

Address	Device
0000	PCIM 200 LCD
1000-1003	6821 PIA (Row 1)
2000-2003	6821 PIA (Row 2)
3000-3003	6821 PIA (Row 3)
4000-4003	6821 PIA (Row 4)
5000-5003	6821 PIA (Row 5)
6000-6003	6821 PIA (Row 6)
7000-7003	6621 PIA (Microswitches)
8000-8007	6840 PTM
D000-D7FF	6116 RAM
E008-E009	6850 ACIA
E00A-E00B	6850 ACIA
F000-F7FF	2716 EPROM
F800-FFFF	2716 EPROM

F2. Program Memory Map

Address	Routine	Description
F800-F92E	STKINT	Initialization
F92F-F94B	-	Main program
F960-FA39	IRQ	IRQ polling routine
FA3A-FA48	MALTST	Potato sensor malfunction test
FA49-FABF	METUPD	Metering update
FAC0-FAEF	UPDATE	Statistics update
FAF0-FB46	CALC	Statistics calculations
FB47-FB4F	ADD	Addition
FB50-FB65	DIVISN	Division
FC00-FC23	CMODE	Change modes
FC24-FC6C	DISPLY	Display refresh
FC6D-FCB0	DELTRW	Change rows
FCB1-FD3C	HEXCON	Code conversion
FD3D-FD4D	LDZERO	Strip leading zeros
FD45-FD58	CLRLCD	Clear LCD
FD59-FD64	DELAY	Delay
FD65-FD6F	DUMP	Character dump to LCD

F3. System Vector Memory Map

Address	Description
F800-F94B	Reset
F960-FB65	IRQ service routine
FC00-FD6F	NIM service routine

F4. ROM Data Memory Map

Address	Description
FD70-FD79	Mode descriptor addresses
FD7A-FD7F	Data block addresses for potato sensor malfunction test
FD80-FD85	PIA addresses for potato sensor malfunction test
FD86-FD8A	Offsets from data block base addresses for performance statistics
FD8B-FD8F	Consecutive miss metering masks
FD90-FDD1	Mode descriptors
FDD2-FDDC	Flags for LCD initialization
FFF0-FFFF	System vectors

F5. RAM Memory Map

Address	Description
D000-D039	Program variables (excluding variables in data blocks)
D100-D1FF	Row 1 data block
D200-D2FF	Row 2 data block
D300-D3FF	Row 3 data block
D400-D4FF	Row 4 data block
D500-D5FF	Row 5 data block
D600-D6FF	Row 6 data block
D700-D73F	User stack
D740-D7FF	System stack

F6. Data Block Memory Map

Address	Description
D#00-D#10	Data block variables (see lines 78-89 in the program listing in Appendix D)
D#11-D#FF	Metering element consecutive miss data

# - Data block row number